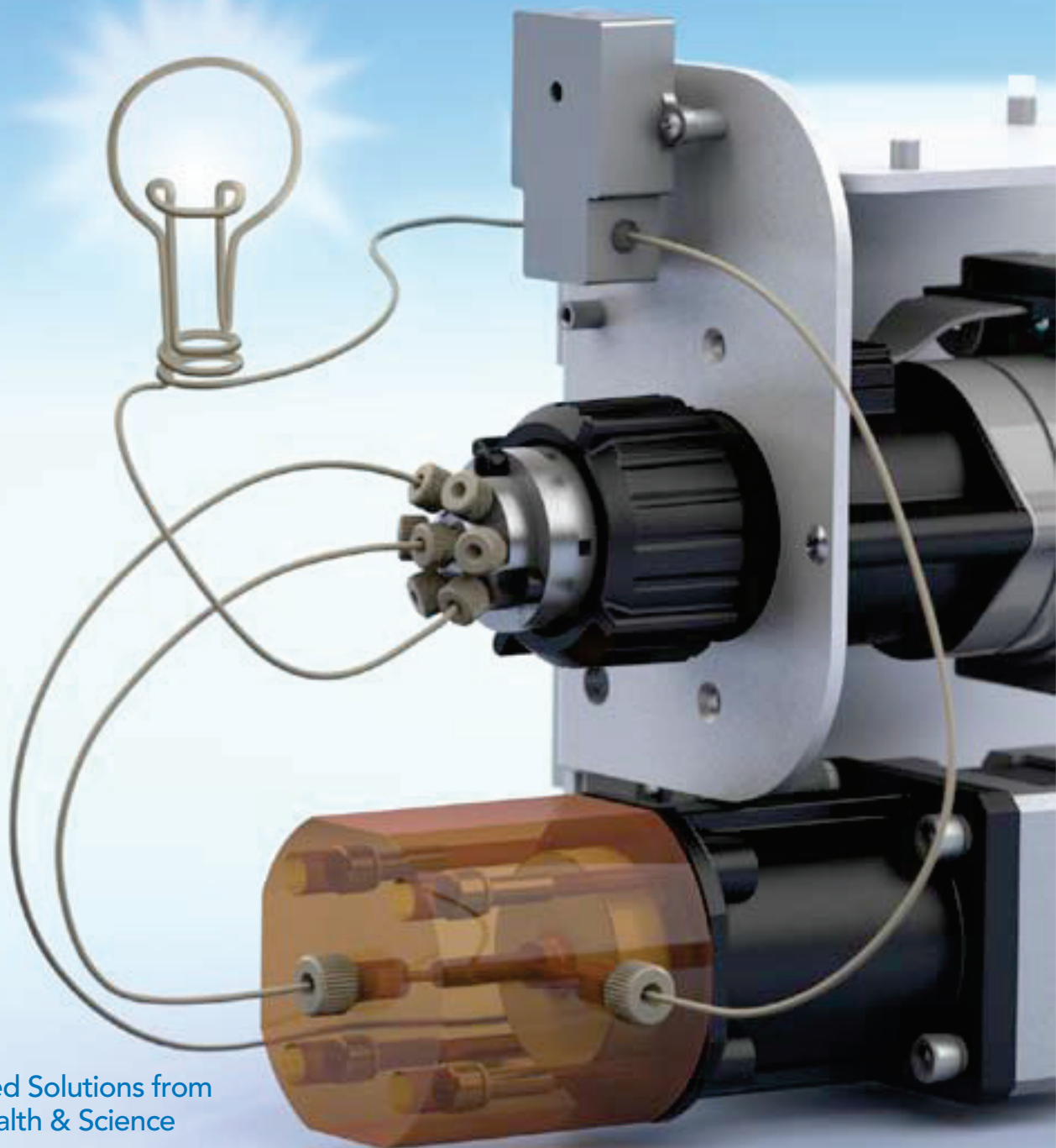


Fluidics Idea Book

Inspiration for instrument designers



Integrated Solutions from
IDEX Health & Science

The Fluidics Idea Book was authored by Darren Lewis, Director of Strategic R&D at IDEX Health & Science.

Dr. Darren Lewis is the Director of Strategic R&D for IDEX Health & Science LLC. Dr. Lewis' work focuses on the design and application of novel fluidic platforms for the Analytical Instrumentation, Biotech, and In-vitro Diagnostics fields. Darren has over a dozen peer-reviewed publications and several patents relating to microfluidics, protein analysis, and DNA sequencing.

In his current role, Darren is responsible for the identification of needs in critical bio analytical fields, the development of high-precision fluidic products, and the integration of these products to create next-generation tools for researchers. Most of Darren's work is highly collaborative fluidic development with customers.

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IDEX Health & Science Integrated Solutions Overview



IDEX Health & Science fluidic developers are often tasked with assisting designers in the planning, optimization, layout, and control of their instrument fluidic path. Flexible systems are configured by IDEX Health & Science to suit OEM needs as we integrate various modular components (e.g., valves, pumps, manifolds, connections, and sensors) into the design as required for a given application.

Historically, instrument designers have been relegated to searching the marketplace for suitable hardware and then integrating that hardware together under some type of control scheme appropriate for the application at hand. These integration and control tasks are complicated by the diverse range of individual component specifications and control methods available in the marketplace.

IDEX Health & Science seeks to reduce the design burden, as we offer a large number of fluidic components suitable for the Life Science markets, and we assist OEM developers in the integration and optimization of these components during their instrument development process.



IDEX HEALTH & SCIENCE INTEGRATED SOLUTIONS OVERVIEW

We believe that designers will achieve faster development time and maintain better control and consistency over their instrument package when they are able to focus on their real priorities (e.g., chemistry, software, assay development, etc.) and we take on the role of optimizing their fluidics.

Our design team has a wealth of experience in the development of fluidic systems and we usually consult with our customers on the layout of their entire fluidic platform. We are experts in the following areas:

- ▶ Minimizing carryover
- ▶ Increasing precision of reagent delivery
- ▶ Handling small volumes of sample
- ▶ Multiplexing and coordinating fluidic devices
- ▶ Understanding the real-time characteristics of fluid flow (e.g., flow pulsation, compressibility, backflow, and pressure equalization, amongst other performance factors)
- ▶ Integration and coordination of subcomponents

As an OEM partner, we assist in all phases of the instrument development cycle (all the way through commercialization), but the focus of this document is to help in some of the earliest design stages: conceptualization, prototyping, and optimization. This Fluidics Idea Book describes several flow path options suitable for performing automated fluidic functions in the LC/MS industry, and it is our intent that you use this document for inspiration during the planning of the fluidic layout for your instrument. Each of the flow path options shown have been developed by IDEX Health & Science, and are offered as starting points for further development discussion with our current — or future — OEM partners.

As we continue to develop solutions, we will add more examples to this booklet.

As with any endeavor in technology, we advise the instrument developer to assess the Intellectual Property around their design prior to development to ensure that no conflicts arise. The ideas presented in this booklet are intended to be starting points for discussion, and no particular applicability, ownership, or reliability is guaranteed for any given application.

IDEX Health & Science Components Basics — Designing with Valves & Pumps



The fluidic ideas described in this document utilize components from many different brands within IDEX Health & Science, and we also incorporate a variety of third-party components as they become necessary for a given development.

In this section of the booklet, we will describe in detail some of our most commonly used building blocks in fluidic instruments. The aim of this section is to show you what our component packages **look like**, and how to **connect them** (i.e., plumb them) to other devices in a design. Often times, these footprint and connection considerations are critical features to evaluate early on in the design process.

Once you are familiar with our component packages and connection methods, we will introduce you to some important electronic control methods described in the third section of this booklet.



Rotary shear valves and their options

For many automated fluid control applications, rotary shear valves are a good choice for the instrument designer. These valves operate by rotating a grooved rotor that is pressed against a mating stator that has a number of ports machined through it. Connections between different ports in the stator are made according to the rotor groove pattern and the angle to which the stator is rotated. Automation is provided using an electromechanical actuator attached to the shaft on the valve.

A typical Rheodyne Titan HT style valve is shown in the illustration below. This compact valve assembly contains a high-pressure shear valve, electronic actuator, and driver board in a very small package, making it ideal for mounting inside an instrument enclosure.

These valves are used for tasks such as solvent selection, flow switching, and injecting samples into flowing streams, amongst a host of other functions. For many years, this type of valve has been the mainstay of the chromatography industry, in no small part due to the fact that they have very cleanly swept internal volumes and can handle larger pressure ranges than similarly-sized solenoid, spool, plug, or pinch valves.

Selecting a rotary shear valve — some shortcuts to success

IDEX Health & Science manufactures several different lines of automated valves for OEM integration under the Rheodyne brand. Selecting the proper valve to use in an application can be an intimidating task for the uninformed, so we will provide some general guidelines and descriptions of the valves in this section.

For the purposes of this discussion, we will be limiting our scope to those valves that are electronically controlled, and are not designed as bench top modules, but are readily implemented into OEM platforms. In the interests of brevity, we have categorized our valve selection tables (below) according to the following priorities:

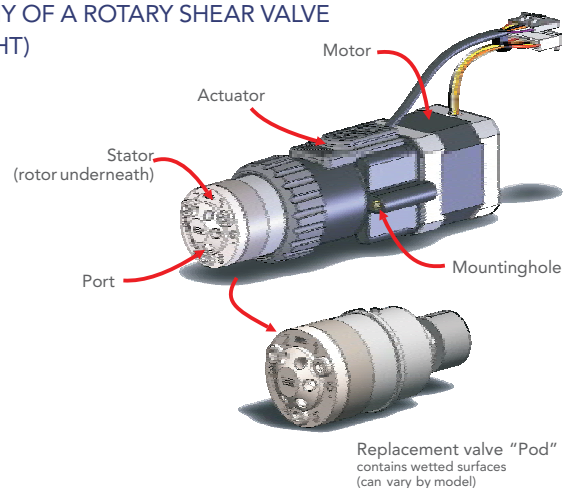
Priority 1: Groove pattern. Our first priority will be to choose a valve based on its rotor groove pattern. This, along with the rotor indexing, defines what the valve will actually do in a fluidic circuit. Many rotor and stator designs share similar patterns, so choosing a valve based on its groove pattern is the first step.

Priority 2: Pressure rating. Selecting a valve according to its pressure handling capability is our second most important priority. Valves rated for too low a pressure than required in a fluidic circuit could get damaged or leak under higher pressure conditions. On the other hand, valves that are over-rated for pressure can possess small passageways that are too restrictive at high flow rates when used in a fluidic application. The valve footprint and actuator style will often vary with pressure handling capability.

Priority 3: Valve geometry (fluidic interface and internal flow path). Our third priority when selecting a valve will be the connection (fitting, tubing, or manifold) options that are available to us for the design. Some designs use compact ferrule clusters to make connections, some designs adapt readily to manifolds, while others utilize a set of industry-standard Metric or Imperial fittings to connect to other devices. The choice of connection will often dictate how user-friendly or serviceable an instrument is in its final form. Additionally, we sometimes have choices between different flow path dimensions inside the valve. Alternative flow path dimensions can allow designers to enhance system performance by optimizing carryover and backpressure concerns.

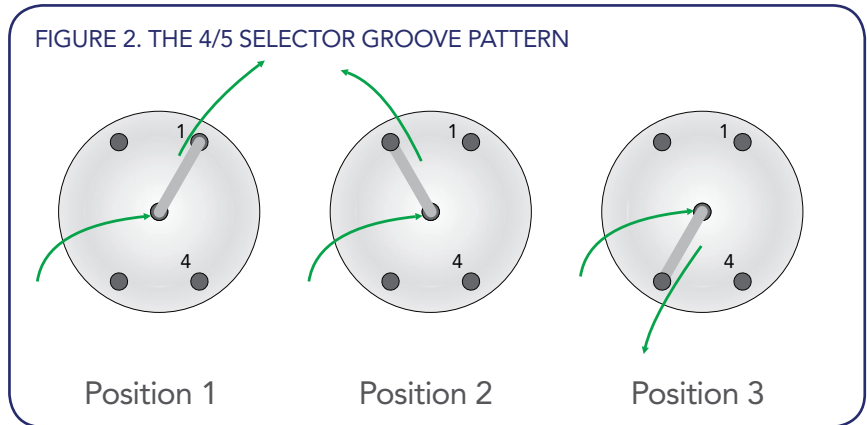
Priority 4: All other differentiators between similar valves. After we have selected valves based on function, pressure handling, and geometrical concerns, valves can further be differentiated according to the materials they are composed of, the footprint of the actuated valve, wetted materials, or designer familiarity, amongst a host of other criteria.

FIGURE 1. ANATOMY OF A ROTARY SHEAR VALVE (ACTUATED TITAN HT)



The 4/5 Selector groove pattern

In the 4/5 selector valve, rotation of the valve rotor allows connection between the center common port and any of the four outer ports around the circumference of the valve stator. Alternatively, different flows from any of the outer ports can be directed through the common port in the valve stator.



| Part # with PCB | Part # without PCB | Notes | Details |
|-----------------|--------------------|--|------------------------------|
| EZ450-000-04 | EZ450-000 | Manifold mounting Ceramic rotor and stator Call us for details | 100 PSI 0.060" Passage |
| EZ450-900-04 | EZ450-900 | Stand alone mounting Ceramic rotor and stator, or PEEK stator Call us for details | 100 PSI 0.060" Passage |

Notes about valve configuration drawings

We will number our valve ports in a counter clockwise direction, starting in the upper right, continuing around the circle. In reality, the position of the first port will depend on mounting, but numbering will always be counter-clockwise.

When we name our valves, we first give the number of positions, then the number of ports (e.g., a 6-position, 7-port selector valve is called a 6/7 Selector).

Our valves are also named contextually, possibly in different application areas than yours, so it is a good idea to look at the rotor groove pattern to identify what we mean by names like "Injector", "Selector", or "Switcher".

Line drawings of rotor flow paths show fluid flow, not necessarily the accurate position of the ports on the valve or the shape of the groove in the valve rotor. For geometrical reasons, some valves (particularly those with a high density of ports) have ports shifted around the stator and at differing angles. Ports are represented by dark circles, rotor grooves by dark grey lines.

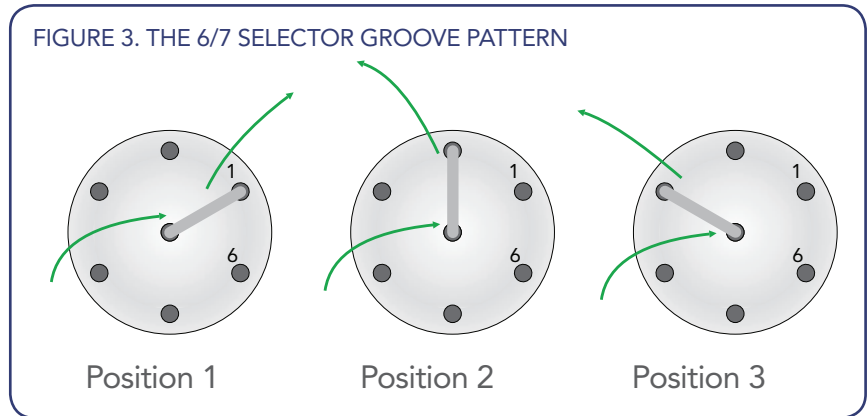
In the drawings, we have drawn arrows representing one possible direction of fluid flow for each valve position.

Not all valve configurations we have constructed are in this document. If you don't see a particular valve configuration, please ask us about it.



The 6/7 Selector groove pattern

In the 6/7 selector valve, rotation of the valve rotor allows connection between the center common port and any of the six outer ports around the circumference of the valve stator. Alternatively, different flows from any of the outer ports can be directed through the common port in the valve stator. The 6/7 Selector valve is available in multiple pressure ranges, as described on this page.



6/7 LOW PRESSURE VERSIONS:

| Part # with PCB | Part # without PCB | Notes | Details |
|-----------------|--------------------|---|---------|
| EZ670-000-04 | | Manifold mounting Ceramic rotor and stator (long lifetime) Call us for details | 102 PSI |
| EZ670-900-04 | | Stand alone mounting Ceramic rotor and stator (long lifetime) Call us for details | 102 PSI |

6/7 HIGH PRESSURE VERSIONS:

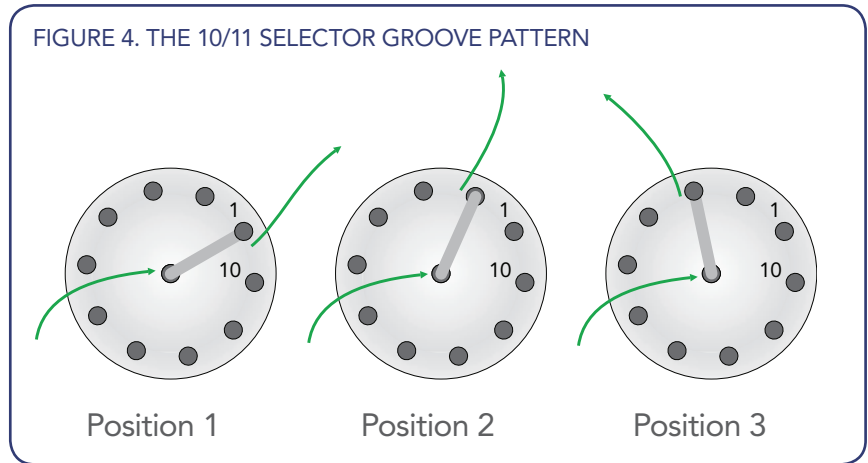
| Part # with PCB | Part # without PCB | Notes | Details |
|---------------------|--------------------|--------------------------------------|---------------------------------------|
| Use Driver 8382-103 | HT706-100 | Ultralife coating 10-32 fittings | 3,000 PSI 0.28 mm (0.011") grooves |
| MHP7970-500-4 | MHP7970-000 | DuraLifell coating 10-32 fittings | 6,000 PSI 0.30 mm (0.012") grooves |

6/7 ULTRA-HIGH PRESSURE VERSIONS:

| Part # with PCB | Part # without PCB | Notes | Details |
|---------------------|--------------------|--|--|
| Use Driver 8382-103 | HT715-105 | Ultralife coating 10-32 fittings | 15,000 PSI 0.28 mm (0.011") grooves |
| Use Driver 8382-103 | HT718-105 | SupraLife coating 10-32 fittings | 18,000 PSI 0.28 mm (0.011") grooves |
| Use Driver 8382-103 | HT725-105 | RPC-15 (Stainless Steel) 10-32 fittings | 25,000 psi 0.25 mm (0.010") grooves |

The 10/11 Selector groove pattern

In the 10/11 selector valve, rotation of the valve rotor allows connection between the center common port and any of the ten outer ports around the circumference of the valve stator. Alternatively, different flows from any of the outer ports can be directed through the common port in the valve stator. The 10/11 Selector valve is available in two pressure ranges, as described on this page.



10/11 LOW PRESSURE VERSIONS:

| Part # with PCB | Part # without PCB | Notes | Details |
|-----------------|--------------------|---|---------------------------|
| EZ011-000-4 | EZ011-000 | Manifold mount Ceramic rotor and stator (long lifetime) Call us for details | 75 PSI 1.5 mm (0.060") |
| EZ011-820-4 | EZ011-820 | Stand alone Ceramic rotor and stator Call us for details | 75 PSI 1.5 mm (0.060") |

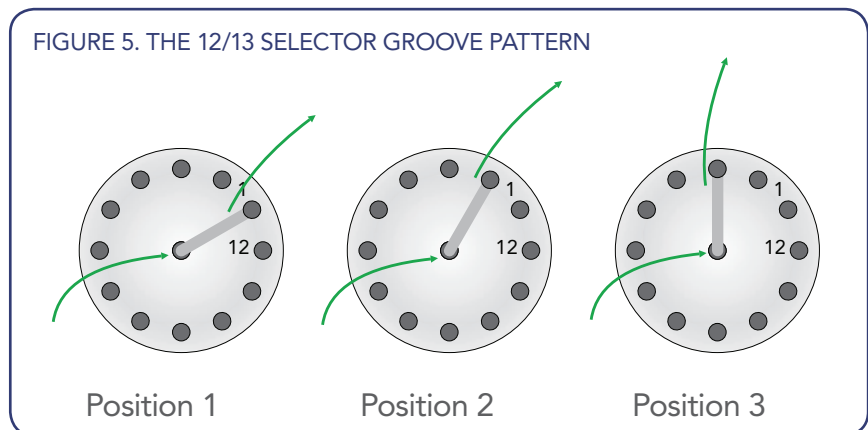
10/11 HIGH PRESSURE VERSIONS:

| Part # with PCB | Part # without PCB | Notes | Details |
|---------------------|--------------------|--|---------------------------------------|
| Use Driver 8382-102 | HT700-107 | Stainless steel rotor and stator 10-32 fittings | 5,000 PSI 0.60 mm (0.024") grooves |
| Use Driver 8382-102 | HT750-107 | PEEK rotor and stator 10-32 fittings | 5,000 PSI 0.60 mm (0.024") grooves |

The 12/13 Selector groove pattern

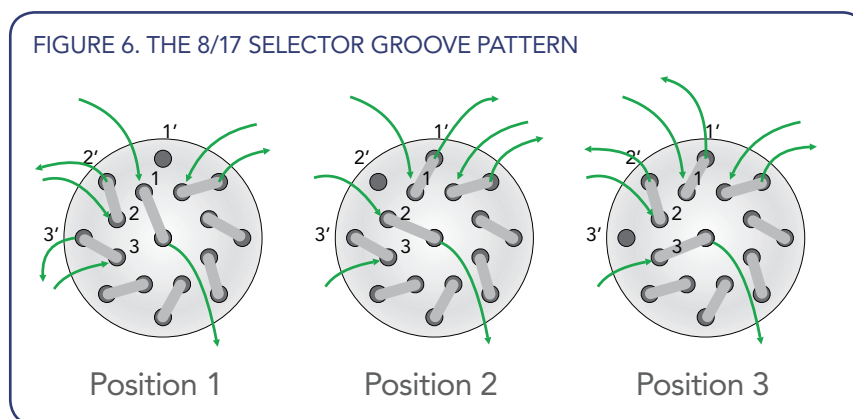
In the 12/13 selector valve, rotation of the valve rotor allows connection between the center common port and any of the twelve outer ports around the circumference of the valve stator. Alternatively, different flows from any of the outer ports can be directed through the common port in the valve stator.

Call us for more information about our 12/13 versions at 1-800-426-0191.



The 8/17 Stream selector groove pattern

The 8/17 stream selector valve is an excellent design for sampling fluid from a flowing stream. This groove pattern allows flow through adjacent ports on the stator (e.g., between ports 2 and 2') but when the rotor is placed in a particular position, flow travels from a numbered inlet port through the center groove on the valve, and out the center port, while the corresponding outlet on the circumference of the valve is blocked.



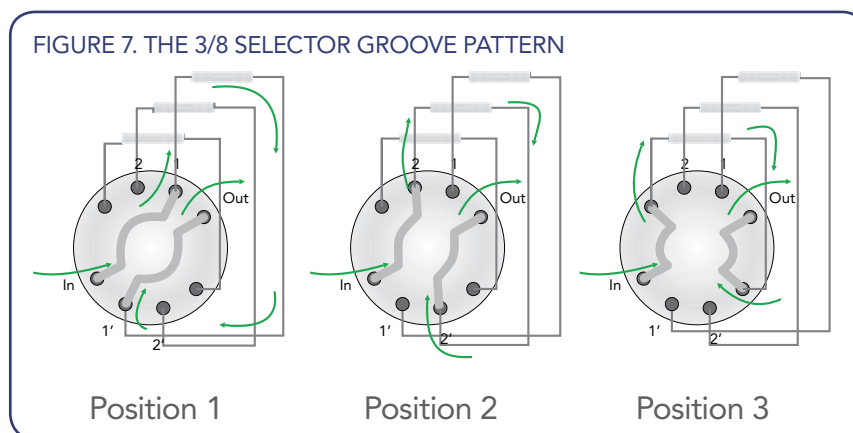
THIS VALVE ONLY COMES IN A LOW PRESSURE VERSION:

| Part # with PCB | Part # without PCB | Notes | Details |
|---------------------|--------------------|---|------------------------------------|
| Use Driver 8382-107 | HT600-100-4 | Stainless steel, Kel-F and UHMWPE wetted materials ¼-28 fittings | 100 PSI 1.5 mm (0.060") grooves |
| Use Driver 8382-107 | HT650-100-4 | PEEK, Kel-F and UHMWPE wetted materials 10-32 fittings | 100 PSI 1.5 mm (0.060") grooves |

The 3/8 Column selector groove pattern

The 3/8 column selector valve was originally designed for switching different chromatography columns into a flow path. If you carefully analyze the flow diagram shown above, you can see that both the inlet and outlet of one of three columns can be switched into the flow path as desired. Although this looks like an image of a set of incredible shrinking rotor grooves, the feat is accomplished by a telescoping interaction between separate rotor and stator grooves. This is a useful valve design for fluidic circuits that require alternative devices to be added to a fluid circuit without the introduction of tees that could cause carryover or dead volume.

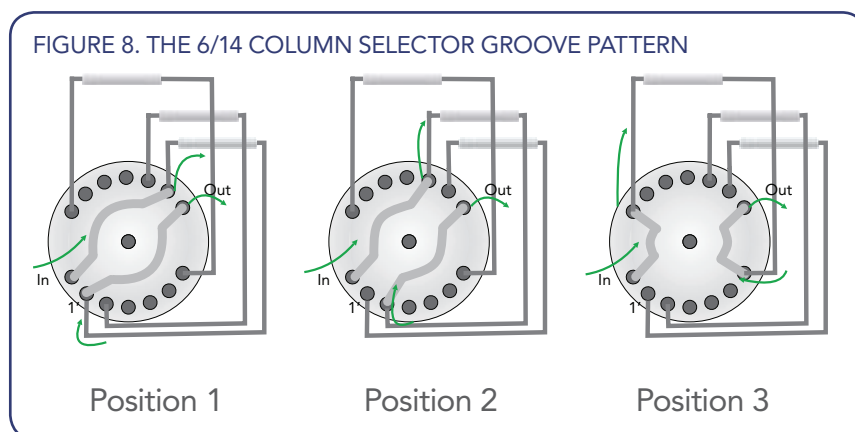
Call us for more information about our 3/8 versions at 1-800-426-0191.



The 6/14 Column selector groove pattern

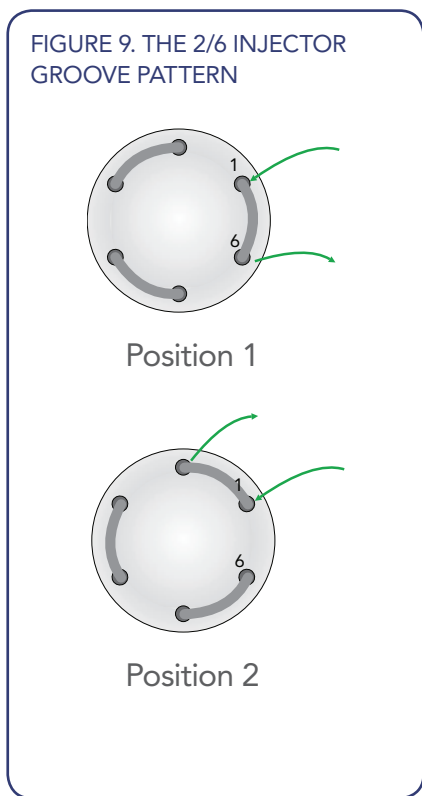
The 6/14 column selector valve was originally designed for switching different chromatography columns into a flow path. If you carefully analyze the flow diagram shown above, you can see that both the inlet and outlet of one of three columns can be switched into the flow path as desired. Although in the image it looks like the rotor grooves are shrinking, functionality is accomplished by a telescoping interaction between separate rotor and stator grooves. This is a useful valve design for fluidic circuits that require alternative devices to be added to a fluid circuit without the introduction of tees that could cause carryover or dead volume.

Call us for more information about our 6/14 versions at 1-800-426-0191.



The 2/6 Injector groove pattern

The 2-position, 6-port Injection/switching valve is another valve developed initially to suit the needs of chromatography, and was initially intended to inject sample plugs into chromatographic systems. These valves can be very handy for simultaneously switching two flowing streams between two different outlets, and are also used for loading functions on auto samplers. These valves are available in a variety of materials and pressure handling capabilities, as described on this page.



2/6 HIGH PRESSURE VERSIONS

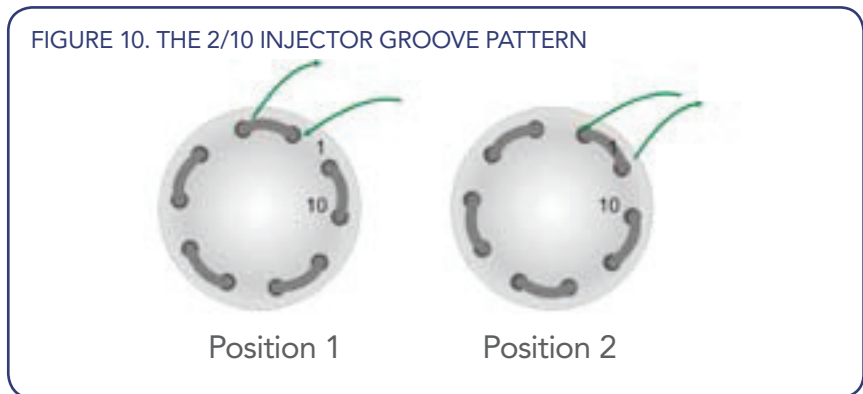
| Part # with PCB | Part # without PCB | Notes | Details |
|---------------------|--------------------|--|---|
| Use Driver 8382-105 | HT700-112 | Stainless steel / PEEK wetted surfaces 10-32 fittings | 3,000 PSI 1.0 mm (0.040") grooves |
| Use Driver 8382-105 | HT750-112 | PEEK wetted surfaces 10-32 fittings | 3,000 PSI 1.0 mm (0.040") grooves |
| Use Driver 8382-105 | HT700-113 | DuraLife and Vespel (Coated Stainless steel, polyimide) 10-32 fittings | 6,000 PSI 1.0 mm (0.040") grooves |
| MHP7900-500-1 | MHP7900-000 | DuraLife coating (Stainless steel, polyimide) 10-32 fittings | 6,000 PSI 0.3 mm (0.012") grooves |
| Use Driver 7770-067 | MHP7907-000 | DuraLife coating (Stainless steel, polyimide) 10-32 fittings Conductive housing (groundable) | 6,000 PSI 0.3 mm (0.012") grooves |
| MHP7920-500-1 | MHP7920-000 | DuraLife coating (Stainless steel, polyimide) 10-32 fittings Vertical port | 6,000 PSI 0.3 mm (0.012") grooves |
| MHP7980-500-1 | MHP7980-000 | DuraLife coating M4 x 0.7 fittings Nano capable | 5,000 PSI 0.1 mm (0.004") Port-to-port volume: 28 nL |
| MHP9900-500-1 | MHP9900-000 | PEEK surfaces 10-32 fittings | 5,000 PSI 0.3 mm (0.012") grooves |

2/6 ULTRA-HIGH PRESSURE VERSIONS

| Part # with PCB | Part # without PCB | Notes | Details |
|---------------------|--------------------|--|--|
| Use Driver 8382-108 | HT715-000 | Ultralife coating 10-32 fittings "Make before break" architecture | 15,000 PSI 0.28 mm (0.011") grooves |
| Use Driver 8382-108 | HT715-121 | UltraLife coating, RPC-10 rotor 10-32 fittings "Make before break" architecture Vertical port | 15,000 PSI 0.28 mm (0.011") grooves |
| Use Driver 8382-103 | HT715-221 | SupraLife coating, RPC-13 rotor 10-32 fittings "Make before break" architecture Vertical port | 15,000 PSI 0.28 mm (0.011") grooves |
| Use Driver 8382-108 | HT718-000 | SupraLife coating 10-32 fittings "Make before break" architecture | 17,400 PSI 0.28 mm (0.011") grooves |
| Use Driver 8382-108 | HT718-110 | SupraLife coating, RPC-13 rotor 10-32 fittings "Make before break" architecture Vertical port | 17,400 PSI 0.28 mm (0.011") grooves |
| Use Driver 8382-108 | HT725-000 | RPC-15 (Stainless Steel) 10-32 fittings | 25,000 PSI 0.25 mm (0.010") passages |

The 2/10 Injector groove pattern

The 2-position, 10-port Injection/switching valve is another valve developed initially to suit the needs of chromatography, and was initially intended to inject sample plugs into chromatographic systems. The extra ports when compared to the 2/6 injector facilitate column switching and a variety of other functions. These valves can be very handy for simultaneously switching two flowing streams between two different outlets, and are also used for loading functions on auto samplers. These valves are available in a variety of materials and pressure handling capabilities, as described on this page.



2/10 HIGH PRESSURE VERSIONS

| Part # with PCB | Part # without PCB | Notes | Details |
|-----------------|--------------------|---|--|
| MHP7960-500-1 | MHP7960-000 | DuraLife coating, Vespel 10-32 fittings | 6,000 PSI 0.25 mm (0.010") grooves |
| MHP7986-500-1 | MHP7986-000 | DuraLifeII coating, Vespel M4 x 0.7 fittings Nano capable | 5,000 PSI 0.1 mm (0.004") Port-to-port volume: 24 nL |
| MHP9960-500-1 | MHP9960-000 | PEEK surfaces 10-32 fittings | 5,000 PSI 0.25 mm (0.010") grooves |

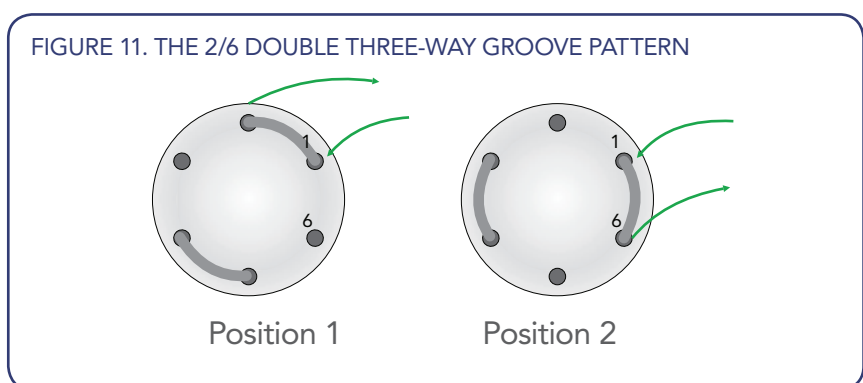
2/10 ULTRA-HIGH PRESSURE VERSIONS

| Part # with PCB | Part # without PCB | Notes | Details |
|---------------------|--------------------|--|--|
| Use Driver 8382-104 | HT715-102 | Ultralife coating, PEEK 10-32 fittings | 15,000 PSI 0.15 mm (0.006") grooves |
| Use Driver 8382-104 | HT718-202 | Ultralife coating, Polyimide 10-32 fittings | 18,000 PSI 0.15 mm (0.006") grooves |

The 2/6 Double three-way groove pattern

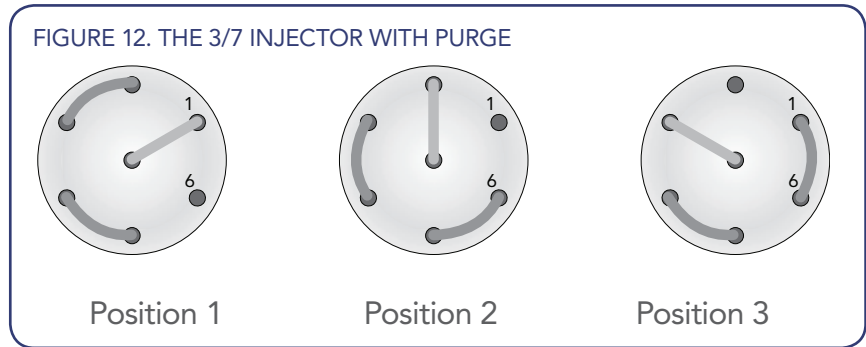
The 2-position, 6-port double 3-way valve has a unique rotor pattern that allows simultaneous switching of two independent 3-way valve paths.

Call us for more information on our 2/6 double versions at 1-800-426-0191.



The 3/7 Injector with purge

This 3-position, 7-port flow switcher valve has a unique rotor pattern that allows simultaneous switching of an injection-valve-style groove with a selector groove.

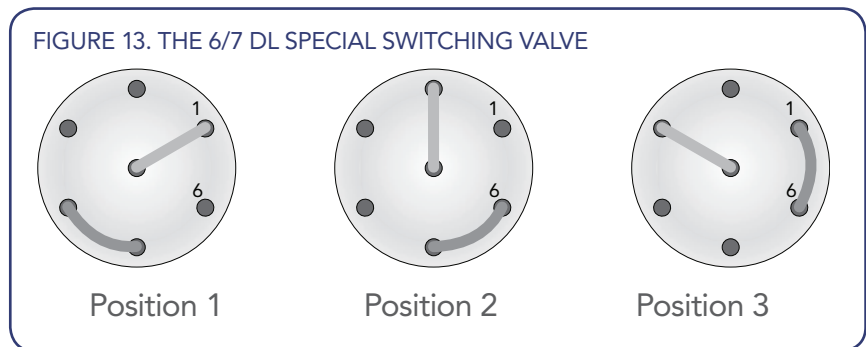


3/7 HIGH PRESSURE VERSIONS

| Part # with PCB | Part # without PCB | Notes | Details |
|---------------------|--------------------|--|--------------------------------------|
| Use Driver 8382-103 | HT703-100 | Stainless steel, PEEK wetted surface 10-32 fittings | 5000 PSI 0.40 mm (0.015") grooves |
| Use Driver 8382-103 | HT753-100 | PEEK wetted surfaces 10-32 fittings | 5000 PSI 0.40 mm (0.015") grooves |

The 6/7 DL special switching valve

This 6-position, 7-port flow switcher valve has a rotor pattern that allows simultaneous switching of a selector groove and a radial groove. This valve forms the basis of many of our pump fill/dispense valves for low flow work that you will see later in this document. This valve is available in all pressure regimes.

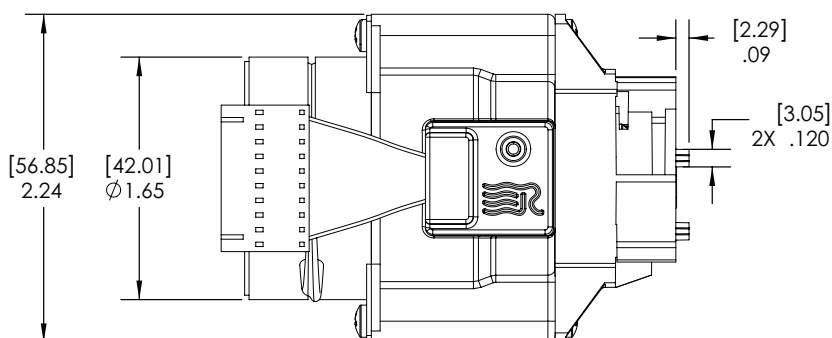
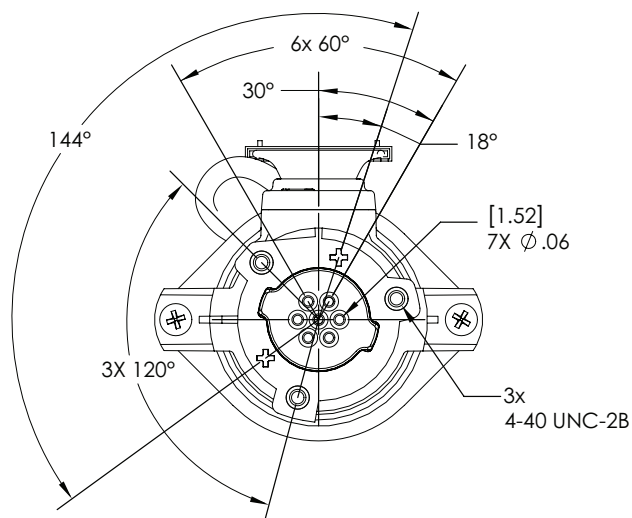


These valves can be constructed from the same product line and materials as any 6/7 Selector. Call us for details at 1-800-426-0191.

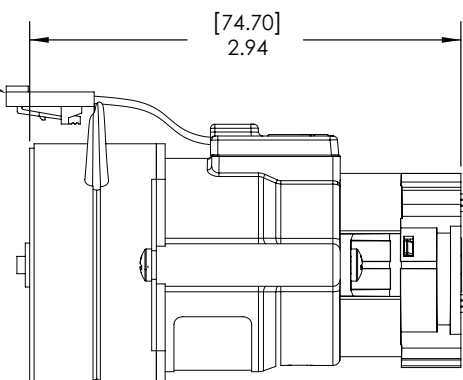
Rotary shear valve/actuator mechanical drawings

Titan EZ styles: dimensions for valves starting with EZ

Dimensions are approximate.
Please see device datasheet for specs particular to a specific model.

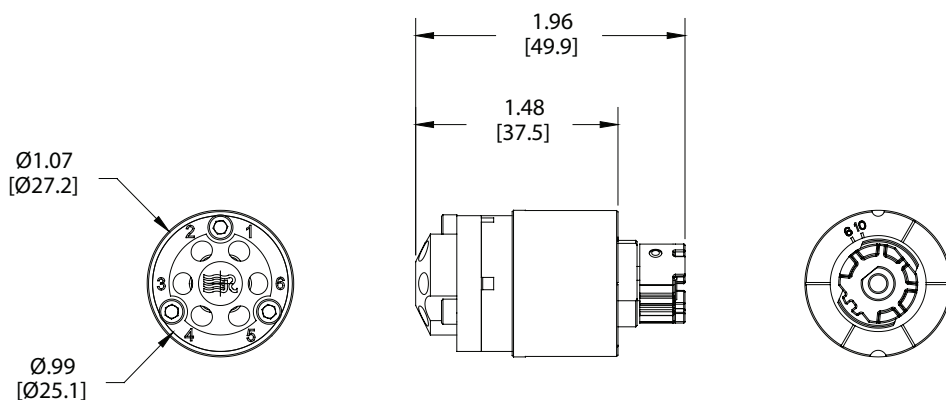
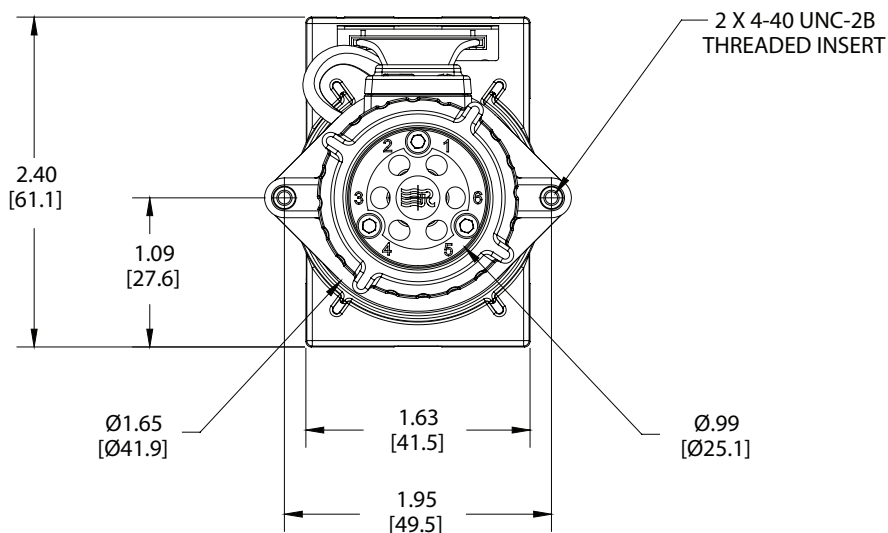
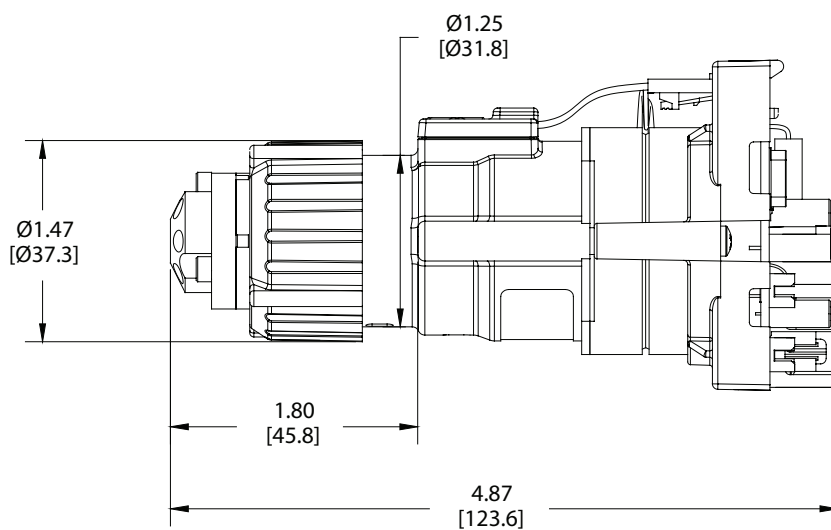


MOLEX CONNECTOR
P/N 5057-9410
MATES WITH MOLEX
P/N 70107A-0009



Titan HP styles: dimensions for valves starting with MHP

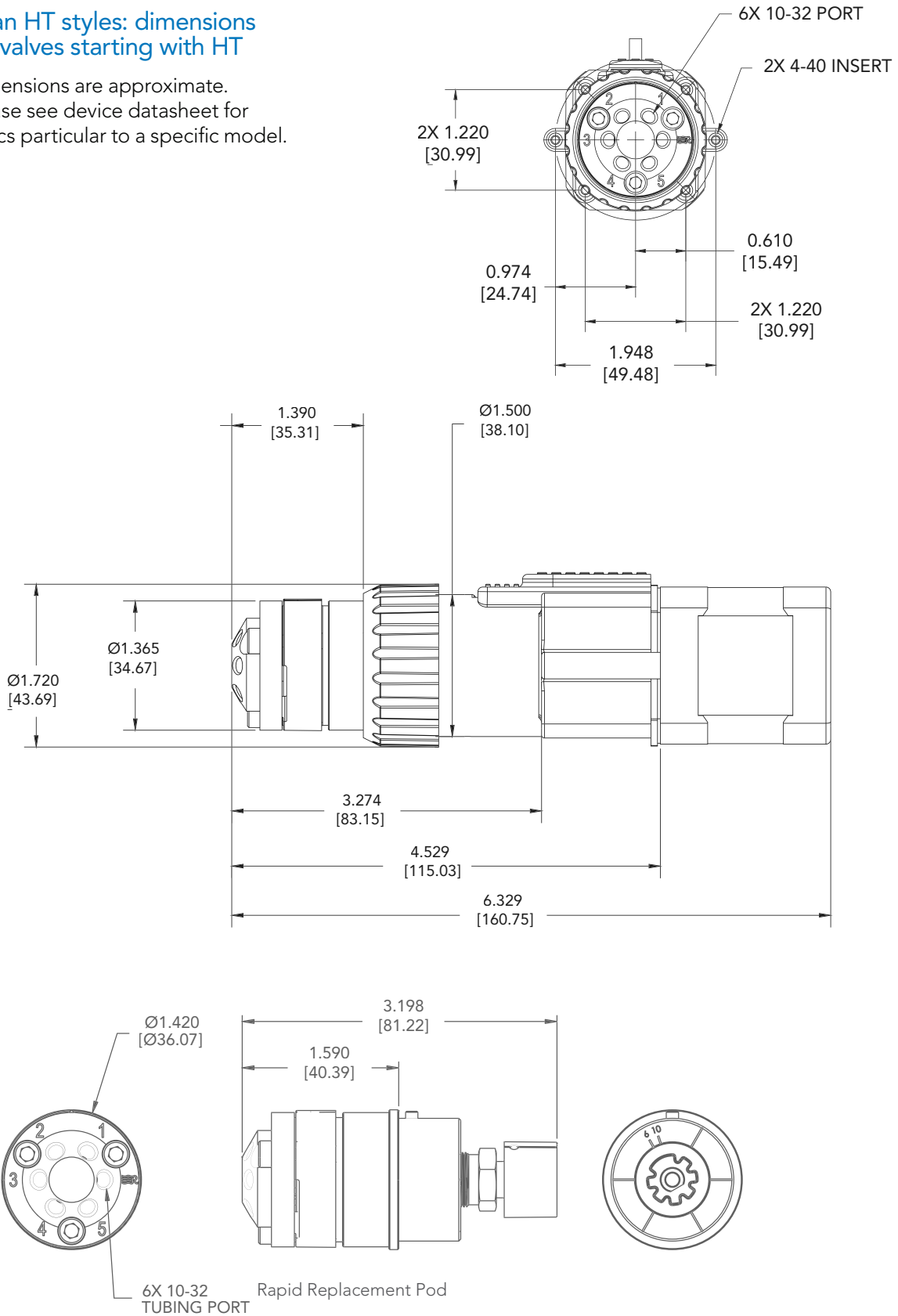
Dimensions are approximate.
Please see device datasheet for specs particular to a specific model.



COMPONENTS BASICS — DESIGNING WITH VALVES & PUMPS

Titan HT styles: dimensions for valves starting with HT

Dimensions are approximate. Please see device datasheet for specs particular to a specific model.



Some friendly advice on effectively using valves in fluidic designs

- ▶ Remember to make sure the valve you are using is rated for the pressure of your design. Take into account the max pressure that the valve could see under any error condition, in addition to normal operating conditions. Valves aren't usually permanently damaged by overpressure, but won't perform as expected when the pressure is too high.
- ▶ Be careful to thoroughly rinse particulate, sticky, gooey, salty, or other icky materials out of the valve on a regular basis. If storing a system for some time, thoroughly rinse the valves clean so that material does not coat the valve surfaces and cause premature failure. If you are working with material that you think can stick to and damage a valve, it is a good idea to add automatic rinse routines to your machine operation.
- ▶ Remember that valves take some time to actuate (typically 100–350 ms from port-to-port). Ports with larger spacing require more time.
- ▶ Be aware of the chemical compatibility of all the reagents used in your system, and make sure you test them against a real live valve during the validation of your equipment. DI water and cola are different.
- ▶ As you design your fluid path, be aware that rotor grooves pass by adjacent ports in the stator as the rotor sweeps through its trajectory. Make sure you don't accidentally let gravity or pressure mix fluids that shouldn't be getting mixed as the rotor moves by. Buffering adjacent ports with a convenient intermediate wash line and balancing pressure can make all the difference in the world.
- ▶ It is always a good idea to look down inside a port before tightening a new fitting in. Look for old ferrules that have been left behind or other debris. This simple practice can save you a lot of grief in the long run. If you notice a fitting feels different than usual as you tighten (e.g., softer or grittier), stop tightening and look inside the port.
- ▶ Make sure that as you tighten a fitting into the valve port you keep the tube pushed all the way to the bottom until the fitting is snug on the tube. This will keep you from accidentally introducing dead volume if the tube moves.
- ▶ As you design equipment, try to have the end user do as little maintenance as possible on a routine basis. It is amazing, but simple tasks in the laboratory can be darn near impossible at the bottom of a mine.
- ▶ If you have a unique application and don't see a valve to suit it, give us a call. We haven't shown them all here. Moreover, we might be able to design a new one!



Positive displacement pumps and their options

IDEX Health & Science manufactures several different versions of positive displacement piston pumps for work in automated analyses. These pumps operate in a similar fashion to syringe pumps, and offer the same level of operational simplicity. A diagram of an S17 version of our pumps is shown in the Figure 14 below.

These pumps drive fluids in the following way: a driver circuit rotates the pump stepper motor in a precisely timed manner. This motor rotation forces an actuator forward or backward according to the direction of motor movement. A piston is attached to the leading end of the actuator, and this piston displaces fluid in the pump head as the actuator moves. Flow rate (or volume dispensed) is determined by the rotation speed of the motor, the diameter of the piston, and the pitch of the threads on the pump actuator lead screw.

During use, some sort of inlet and outlet flow control valves must be added to the pumps in order to facilitate filling and dispensing of fluids. These valves could be simple check, rotary shear, or solenoid types, but must be synchronized with piston movement. (It is fortunate that IDEX Health & Science offers many

choices of valves for your use. In later sections of this document, we discuss the options for valve control using our driver circuitry and firmware.)

Our Sapphire Engineering brand positive displacement pumps differ from regular syringe pumps in several important ways:

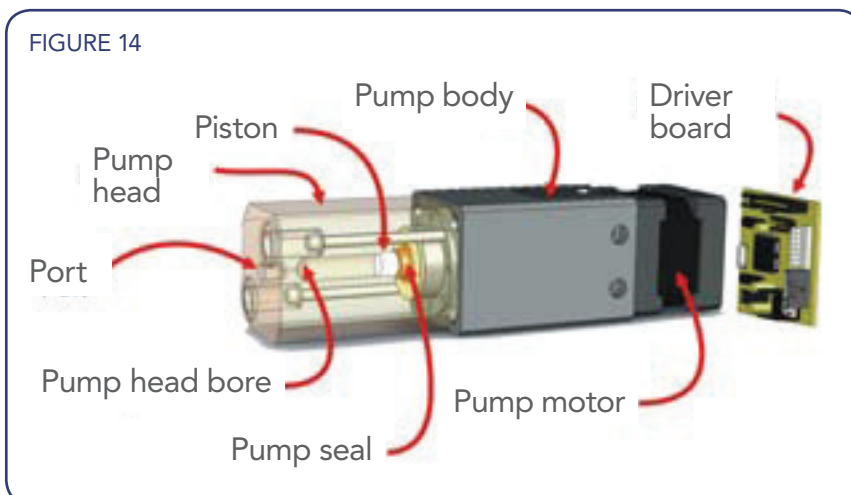
1. The IDEX Health & Science pumps possess fixed seals at the rear end of the pump bore, and the piston slides through the seal. This differs from a typical syringe pump that has a sliding seal on the moving plunger. Our sealing method tends to provide longer lifetime because the seal is active (meaning it provides sealing force proportional to the fluidic pressure), and because the piston surface is very smooth, thus reducing wear.
2. Because our pistons are machined from very hard materials with high precision and the displacement volume of the piston is dependent on the piston diameter and length, it follows that precision machined pistons can achieve very high flow precision. Often, this precision is much better than equivalent-sized syringe pumps.

3. The head on our pumps is not disposable, and is intended to last the lifetime of the pump.
4. The drive train on our pumps has fewer moving parts than typical syringe pumps, which often require offset belts, gears, pusher blocks, and other mechanical parts to achieve pumping.
5. In general, our small-diameter piston versions of the pumps can dispense at much higher pressure than their syringe pump analogs. For some 250 microliter versions of our pumps, outlet pressure can exceed 5,000 PSI (340 bar). In very special designs, 10,000 PSI (680 bar).

How to successfully integrate a positive displacement pump into OEM equipment

To integrate one of our positive displacement pumps into your equipment, you (or we) must provide the following infrastructure:

1. **Stepper motor driver circuitry.** Our pumps operate using bipolar stepper motors. These motors typically have either 1.8 or 0.9 degree step angles, and, depending on pump model, require from 0.5 to 1.5 Amps per phase. The pump driver must be able to operate in forward and reverse direction, and for fast movements, acceleration profiles are desirable. Pulse-width modulated (PWM) drivers provide high efficiency operation and wider velocity ranges than traditional passive drivers. PWM frequencies in excess of 20 kHz will reduce audible noise from the motor. **We can provide complete driver solutions,** including micro stepping with high-level command sets for ease of integration.



2. Home sensor detection. The pumps do not contain absolute encoders, but do have home sensors located on one end of the piston travel (either the fully dispensed or fully aspirated position). This means that upon power up, before you make any other pump movements, you need to home the pump by moving to the sensor, resetting a step counter, then keeping track of motor steps as you operate the pump. Our home sensors are optical types, operating from +5V, with the output signal pulling low upon homing. For more details, see the pump data sheet. **Homing functionality is taken care of with our driver package.**

3. Ability to calculate where the piston is. Once the pump has been homed, you need to keep track of its position. The main objective here is to prevent the piston from overshooting the end of travel and becoming stuck. You can keep track of position using an external encoder (optional), or by keeping track of motor steps from the stepper motor driver. **If you use our driver circuitry, position monitoring is taken care of by our firmware.**

4. Valves. To fill the pump, you need to allow flow into the head by opening a valve, and to dispense, you will need to close the fill valve and open a dispense valve, thus allowing fluid to flow from the pump to your target. If you use a single-port pump, you can achieve this filling and dispensing using a single three-way valve. Two-port pumps allow better rinsing and easier bubble purging, but need slightly more complex valve schemes. For correct operation, the valve opening and closing needs to be synchronized with the direction of piston

movement. **If you use our driver package, proper valve coordination is taken care of for you** (see next section for details).

5. Software. Our pumps are OEM solutions, so they are generally not supplied with control panels, touch screens, dials or knobs. We can provide software support to operate the pumps from a PC, and we can provide source code examples and all the operational details you will require to write your own control software. **If you use our driver circuitry, we can offer start-up software to get you going.**

To integrate one of our positive displacement pumps into your equipment, **the following infrastructure pieces are optional**, but could significantly enhance performance, depending on your application:

1. Encoder support. Encoder options are available on most of our pump models. If you choose the encoder option, your driver board (or another control component) must be capable of reading the encoder. This encoder readout can serve to provide position information and to detect a stall. Our encoders are typically 400 PPS Quadrature types with Z index.

2. Debubblers/degassers. All pumps operate more reliably when gas bubbles are not allowed to form in the fluidics. It is an unfortunate consequence that outgassing can occur when pressure drops rapidly, convection is created, temperature rises quickly, or when differing solvents mix together, amongst other causes. The best remedy for this outgassing is to remove the gases (usually dissolved air) from the fluid before it enters the pump. IDEX Health & Science

provides a range of debubblers and degassers for OEM incorporation under the Systec brand name.

3. Pressure sensors. Inline pressure sensors can be very handy for optimizing protocols, providing experimental feedback, or for detecting plugs or leaks.

4. Flow sensors. For especially demanding applications, particularly at very low flows or when significant pressure changes occur downstream of a pump, flow sensor feedback can be very beneficial in maintaining pump precision. We provide an example of a flow-feedback pumping solution later in the Ideas section of this booklet.

5. Seal wash. For non-pump experts, this might sound like an Arctic misadventure, but for applications in which salty solutions may leave residue on the piston seal, we can provide separate ports for washing the seal and removing salt build-up. This will improve the lifetime of the seal and pump.

Selecting a positive displacement pump—some help in getting it right

Our Sapphire Engineering positive displacement pumps are available in a variety of forms, wetted materials, pressure handling capability, and precision capabilities, depending on your application needs. In this section, we will provide information to help you understand differences between the pumps we offer, and to help you pick the right pump. Please contact us for help in selecting the right pump for your application.

What you need to figure out in order to pick a pump:

1. Know your specs.

Before deciding on a pump, you will need to answer several relevant questions:

- **What pressure range does my system need to handle?** You will need to choose a pump that has a higher pressure rating than your application. In general, the V-Series are ideal for low-pressure, high-flow applications and the S17 for high-pressure, low-flow applications.
- **Is my flow continuous or pulsed?** For many applications, it is OK for pumps to dispense their volume of fluid during an analysis, then refill quickly before the next analysis is started. In other circumstances, continuous flow is required. Because our piston pumps have finite volumes, continuous flow requires alternating between two piston pumps with valves controlling the fill/dispense cycles. Alternatively, and especially at lower pressures, different types of pumps may be employed for some applications.

- **What are the maximum and minimum flow rates for my application?** These rates will help us determine the optimum pump size (displacement volume). Smaller displacement pumps offer more precision and higher pressure capability, but can't operate at high flow rates. Larger pumps operate well at higher flow rates, but are not as precise at lower rates.
 - **What are my precision specs for this application?** This information, alongside the max flow rate specification, will help us decide the appropriate actuator screw pitch, stroke length and volume for the pump. The 40-pitch S17 offers best precision, but is amongst the costliest pump systems.
 - **What are the maximum and minimum dispense sizes for my application?** For applications requiring discrete aspiration and dispense steps, knowing these will help us select the best pump volume. In general, matching the pump volume to the most critical dispense size offers the best precision.
 - **What liquids will I be pumping?** This will determine the materials we choose for the pump head. The V and VP17 pumps are offered with molded acrylic heads ideal for IVD applications using a DI water or saline buffer solution while the S and VFP series pumps are available in PEEK, Ultem, and stainless steel versions offering increased chemical compatibility.
2. Know how you will be operating the pump.
- **Will this pump be required to quickly change flow rates, or is set point stability the most important feature?** This information is used when we select seal and port geometries for your application.
 - **Will the end user be required to regularly change pump tubing?** This information will affect our choice of fittings.
 - **Will the pump be required to change solvent regularly?** Systems that require efficient changeover of solvents are better designed when the pump has two ports to allow flushing.
 - **What lifetime do I need for my application?** The answer may determine which type of piston pump you need, along with whether or not features such as seal wash are desirable.
3. Know how the pumps get mounted in an instrument.
- Some pump designs are meant to be mounted on their side, while others mount with the bore pointing upwards. You need to make sure you study the pump dimensional drawings and make enough room and support for the pump.

The S17 line of pumps:
high-pressure range,
highest precision

The S17 pump line is so named because it is based on a NEMA 17 size motor on its linear actuator. This pump series offers a 1.125" stroke length, with several different port and fittings options.

Footprint: Overall pump dimensions are given in the diagram below, for your reference.

Port orientation options: The S17 pumps have three common port orientation options: vertical with 2 ports, horizontal with 2 ports, and vertical with one port. The first option, vertical with 2 ports offers optimum bubble clearing and rinsing for many applications, while the third option, vertical 1 port, offers efficient bubble clearing and valve simplicity. The horizontal configuration is very useful with compact mounting requirements.

Port geometry options:

IDEX Health & Science can provide S17 ports in several different thread patterns and geometries, depending on how the plumbing needs to interact with the rest of the system. For diagnostic and low-pressure equipment, the most common ports are either 1/4-28 flat bottom fittings or M6 flat bottom. For analytical work and higher-pressure applications, M4 and 10-32 tend to be the most common.

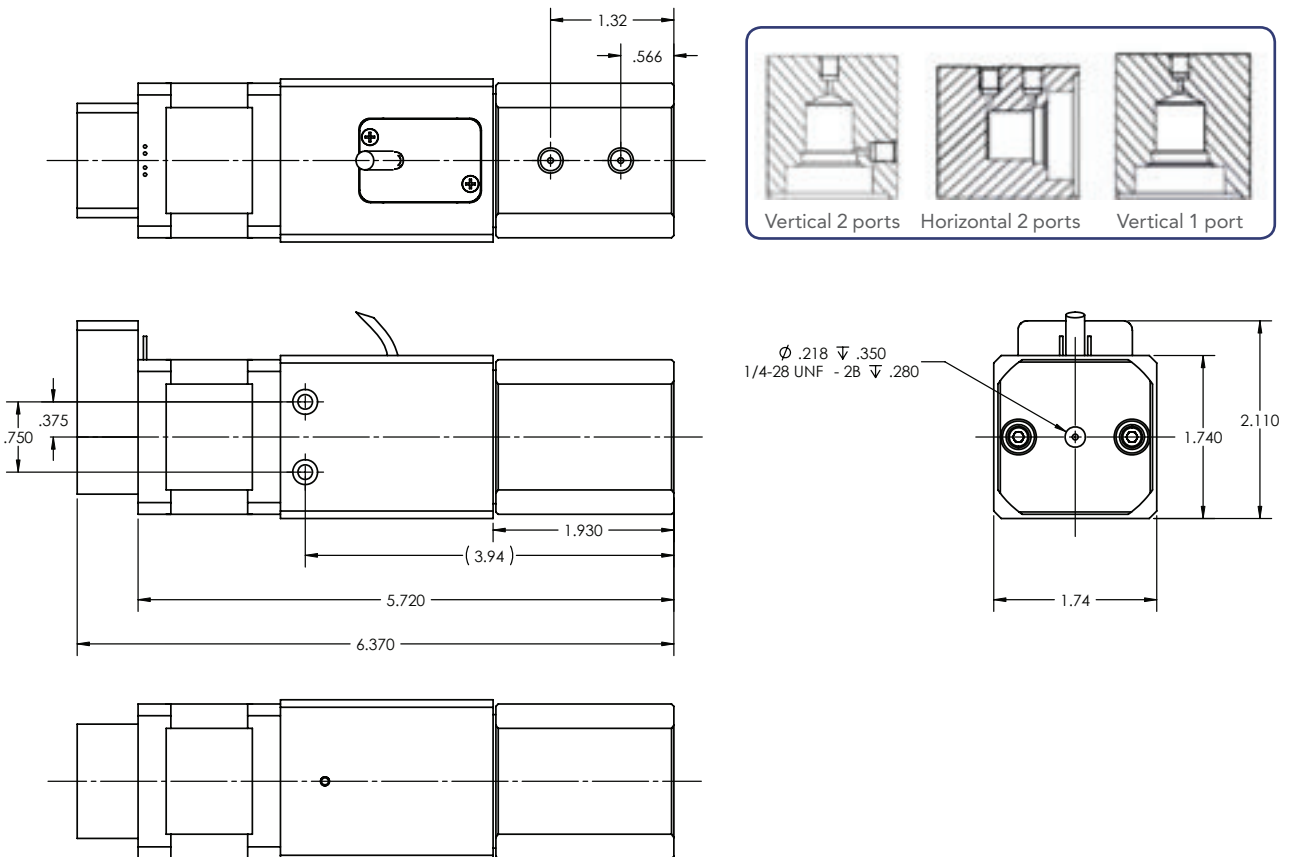
Materials: The S17 pumps are offered in a variety of different pump head materials to suit the demands of diverse applications. For applications that use mainly aqueous-based solvents and few organics, we offer transparent acrylic pump heads. For more harsh solvents, clear pump heads can be manufactured out of Ultem polymer. Ultimate chemical compatibility is obtained by using 316 stainless steel, titanium, or PEEK polymer.

Pump head displacement

volume: Depending on needs (described above), the S17 pumps are offered in several different displacement volumes: 100 µL, 250 µL, 500 µL, 1.125 mL, 2 mL, and 5 mL. We can sometimes do other sizes upon request.

Actuator lead screw pitch:

Precision and speed tradeoffs can be made by customizing the lead screw pitch. Higher pitch screws create better step precision, but take more overall motor steps to achieve a given dispense volume. Piston driving forces can also be higher with higher pitched screws, so pressure rating can also increase. The S17 is commonly created with 16-, 20-, and 40-pitch screws, depending on application need.



The VFP17 line of pumps: life-of-instrument performance for low- and medium-pressure applications requiring excellent precision and accuracy

The VFP17 pump line is built upon our 0.5" stroke length V-Series platform and has a NEMA 17 size motor on its linear actuator. This pump series offers stable performance over its 5 million cycle life and can be built with several different port, fitting and head material options.

Footprint: Overall pump dimensions are given in the diagram below, for your reference.

Port orientation options: The VFP17 pumps have three common port orientation options: vertical with 2 ports, horizontal with 2 ports, and vertical with 1 port. The first option, vertical with 2 ports offers optimum bubble clearing and rinsing for many applications, while the third option, vertical 1 port,

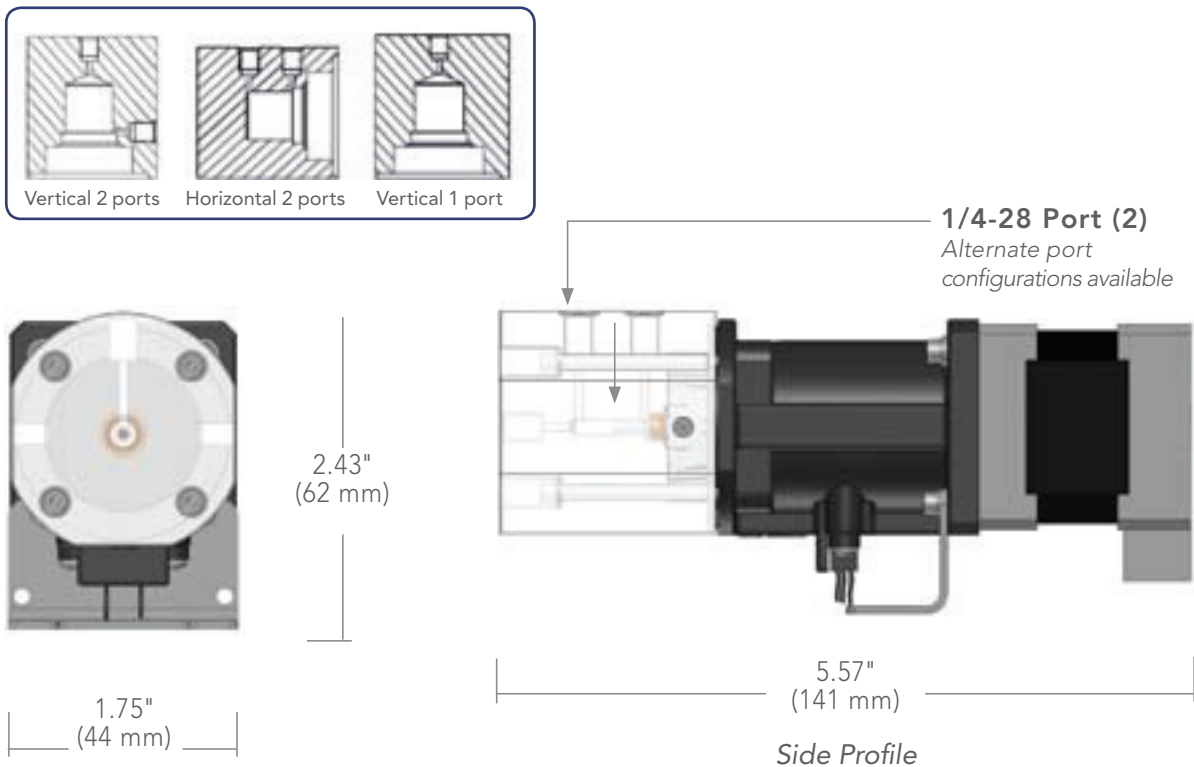
offers efficient bubble clearing and valve simplicity. The horizontal configuration is very useful with compact mounting requirements.

Port geometry options: IDEX Health & Science can provide VFP17 ports in several different thread patterns and geometries, depending on how the plumbing needs to interact with the rest of the system. For diagnostic and low-pressure equipment, the most common ports are either 1/4-28 flat bottom fittings or M6 flat bottom. For analytical work and higher-pressure applications, M4 and 10-32 tend to be the most common.

Materials: The VFP17 pumps are offered with several different pump head material options to suit the demands of diverse applications. For applications that use mainly aqueous-based solvents and few organics, we offer transparent acrylic pump heads. For more harsh solvents, clear pump heads can be manufactured out of Ultem or PEEK polymer.

Pump head displacement volume: Depending on needs (described above), the VFP17 pumps are offered in several different displacement volumes: 25 µL, 50 µL, 100 µL, 250 µL, 500 µL, 1 mL, 2.5 mL, and 5 mL. We can sometimes do other sizes upon request.

Actuator lead screw pitch: Precision and speed tradeoffs can be made by customizing the lead screw pitch. Higher pitch screws create better step precision, but take more overall motor steps to achieve a given dispense volume. Piston driving forces can also be higher with higher pitched screws, so pressure rating can also increase. The VFP17 is created with 20- or 40-pitch screws, depending on application need.



The VP17 and V17 line of pumps: life-of-instrument performance for low-pressure and price-conscious applications

The V17 and VP17 pump lines are two other value-priced options that utilize advanced manufacturing techniques and are constructed with molded heads. These pump series are built upon our 0.5" stroke length V-Series platform, with several different port and fittings options. Overall, this pump type has a lower pressure capability than the S17 and VFP17 lines, and more limitations on materials, but offers excellent value for the most price-conscious applications. The main differentiator between the VP17 and the V17 pumps is that the V17 lifetime is specified for 2 million piston cycles and the VP17 lifetime is specified for 5 million piston cycles.

Footprint: Overall pump dimensions are given in the diagram below, for your reference.

Port orientation options: The V17 and VP17 pumps have only one port orientation option, vertical with 2 ports, as shown in the above diagram. Either port can be plugged to suit single port applications.

Port geometry options: IDEX Health & Science can provide V17 and VP17 ports in one of two different thread patterns: 1/4-28 flat bottom fittings or M6 flat bottom.

Materials: The V17 and VP17 pumps are offered in only transparent acrylic pump heads.

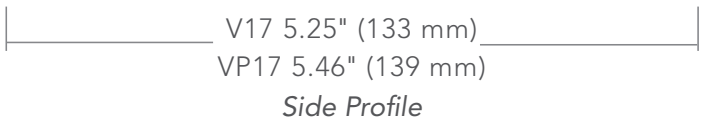
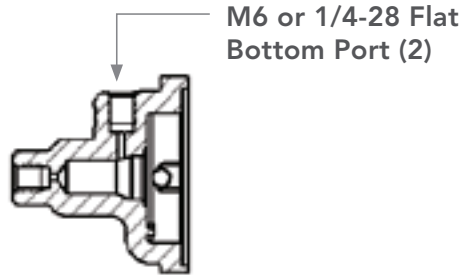
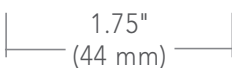
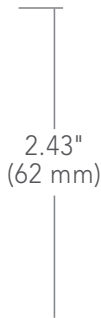
Pump head displacement volume: Depending on needs (described above), the V17 and VP17 pumps are offered in several different displacement volumes: 25 µL, 50 µL, 100 µL, 500 µL, 1.0 mL.

Actuator lead screw pitch:

Precision and speed tradeoffs can be made by customizing the lead screw pitch. Higher pitch screws create better step precision, but take more overall motor steps to achieve a given dispense volume. Piston driving forces can also be higher with higher pitched screws, so pressure rating can also increase. The V17 and VP17 pumps are created with 20- or 40-pitch screws, depending on application needs.

V17 (2M Cycles)
High precision

VP17 (5M Cycles)
Longer life



Step precision for various pump models

The following table summarizes the step precision comparison between our pump series:

| Pump Volume (µL) | 20 T P I pitch (µL/step) | 40 T P I pitch (µL/step) | 20 T P I pitch (µL/step) | 40 T P I pitch (µL/step) | Maximum Un-swept Volume (µL) | | | Maximum Seal Wash Volume (µL) | | |
|------------------|---------------------------|---------------------------|---------------------------|---------------------------|------------------------------|--------|-----|-------------------------------|-------|-----|
| Pump model | V17/VP17/VFP17 | V17/VP17/VFP17 | S17 | S17 | V17 / VP17 | VFP 17 | S17 | V17 / VP17 | VFP17 | S17 |
| 25 | 0.0125 | 0.0063 | N/A | N/A | N/A | 27.8 | NS | N/A | 24.5 | NS |
| 50 | 0.025 | 0.0125 | 0.0112 | 0.0056 | 82 | 54.3 | NS | 44.3 | 32 | NS |
| 100 | 0.0501 | 0.0251 | 0.0224 | 0.0112 | 107.2 | 72.3 | NS | 54.1 | 41.9 | NS |
| 250 | 0.125 | 0.0625 | 0.0556 | 0.0278 | N/A | 136.6 | NS | N/A | 41.2 | NS |
| 500 | 0.2499 | 0.125 | 0.1667 | 0.0556 | 273.6 | 224 | NS | 101.7 | 89.4 | NS |
| 1000 | 0.5 | 0.25 | 0.333 | 0.167 | 427.4 | 320.7 | NS | 158.2 | 145.3 | NS |
| 2500 | 1.2496 | 0.6248 | N/A | N/A | N/A | 564.4 | NS | N/A | 246.9 | NS |
| 5000 | 2.4996 | 1.2498 | 1.110 | 0.555 | N/A | 819.8 | NS | N/A | 376 | NS |

Notes: Stroke length for VFP: 0.5", Stroke length for S17: 1.125". N/A=Not applicable, NS=No standard. Assumes 200 step, 1.8 degree step motor

Tips on plumbing components together in fluidic circuits

In the previous sections, we have described some of the basic building blocks that are used in creating fluidic circuits like those presented in the Ideas section of this booklet. Here, we'd like to give some tips for those folks that are required to hook everything together.

Almost all about fittings

We have an excellent primer booklet on making connections properly, and it includes very nice descriptions of all the different liquid connection types that you are likely to encounter¹. We have also included background information here from the IDEX Health & Science webpage for your reference.

Fittings are typically comprised of a nut and a ferrule and have the important function of providing the physical connection of tubing throughout most systems. While simple in function, fittings exhibit some complexity regarding their description and how they are used.

To properly describe the type of fitting necessary for a particular connection, several things must be taken into account. General descriptive terms include the geometry of the receiving port (coned or flat-bottom); the size tubing for which the fitting is designed; and a mechanical designation of the threads on

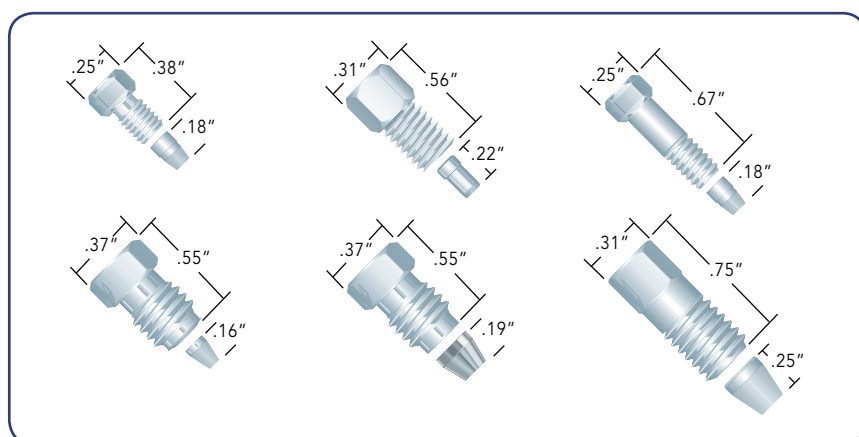
the nut portion of the fitting (e.g. 10-32, 1/4-28, etc.). Beyond these general categories, fittings may be classified by the overall dimensions (length, maximum diameter, etc.) and the type of material from which they are manufactured: stainless steel or polymer-based.

Using stainless steel fittings

Although restrictive in use and non-universal in application, stainless steel fittings are the most popular fitting used on HPLC systems today, due to their solvent inertness and high-pressure holding abilities. These fittings usually come in a conical configuration, requiring special care to be taken in choosing the proper fittings for any given mating port.

In general, male stainless steel nuts vary in overall length and thread length, and these two dimensions are often manufacturer-specific.

Also, stainless steel ferrules are available in a variety of shapes. Therefore, to ensure proper operation and long life from the chosen fitting, it is best to use fittings specifically designed for use with a particular manufacturer's port. Pictures of different nut and ferrule geometries are presented in the picture below.



Swaging for the first time

Besides the array of fittings available for use with different manufacturers' equipment, stainless steel fittings exhibit one attribute which separates them from polymer-based fittings; in order to use them properly, the ferrule portion of the fitting must be swaged — or permanently attached — to the tubing it is connecting. To do this properly, we recommend the following procedure:

- Place the nut and ferrule, in that order, on the tubing. Place the loosely assembled fitting into a mating port, and tighten the nut finger tight. While ensuring the tubing is bottomed out inside the mating port, tighten the nut with a wrench an additional 3/4 of a turn. The ferrule should now be permanently attached to the tubing.

Because the ferrule is permanently attached to the tubing, and because of standard machining tolerances, we highly recommend that any pre-swaged stainless steel fitting only be used in the mating port into which it was initially swaged. Failure to do this may result in dead volume or solvent leakage.

Attaching pre-swaged tubing

For proper tightening of a pre-swaged stainless steel fitting into its mating port, try wrench tightening only an additional 1/4 to 1/2 of a turn past finger tight, followed by subsequent monitoring of the connection for any leaks. Should leaking occur, simply continue to tighten the fitting a little at a time until the leak stops. Should it become necessary to tighten the fitting more than one complete revolution past finger-tight to stop leaks, the fitting should be replaced, as excessive tightening is typically indicative of damaged parts.

¹ All About Fittings, Copyright © John W. Batts, IV, published by IDEX Health & Science LLC, 2011

Using polymer-based fittings

Unlike their stainless steel counterparts, polymer-based fittings are typically non-restrictive and fairly universal in function. And while stainless steel fittings remain the most popular fitting used with HPLC systems, polymer-based fittings are continuously gaining in popularity not only due to their near-universal application but also based on their ease of use.

Because of the nature of polymer-based fittings, the same degree of care does not have to be taken when choosing the proper fitting to mate with a specific manufacturer's receiving port. Primarily, the only two characteristics of the fitting that must be known are the geometry (coned or flat-bottom) of the receiving port and the thread dimensions.

Also, and again unlike stainless steel fittings, polymer-based fittings do not permanently attach to a piece of tubing and usually do not require the use of any tool (besides your fingers!) to properly tighten and use. Additionally, these fittings often come in a variety of polymers, including PEEK, PTFE, Tefzel, Delrin, PPS, polypropylene, and others, for maximum cost and solvent resistance flexibility.

Some friendly advice on effectively using fittings and tubing in fluidic designs

- ▶ Be wary of re-using (i.e., moving) your permanently swaged fitting types to other ports. The length of tube exposed after the ferrule (and the geometrical details of the ferrule) can vary on different ports. This means that void volumes, leaks, or port damage could occur if incorrect pre-swaged ferrules are swapped between different fittings.
- ▶ Don't use stainless steel ferrules in polymeric ports. These ferrules will damage the receiver ports. You can use any type of ferrule in a stainless steel port.
- ▶ We stole this from the Valves section, but it bears repeating here: It is always a good idea to look down inside a port before tightening a new fitting in. Look for old ferrules that have been left behind or other debris. This simple practice can save you a lot of grief in the long run. If you notice a fitting feels different than usual as you tighten (e.g., softer or grittier), stop tightening and look inside the port.
- ▶ Take care when routing tubing on your instrument. We often find that careless routing can affect flow precision and accuracy, particularly if tubing is attached (or otherwise barnacled, bubble-gummed or duct-taped) to moving, vibrating, or heating objects. Just because your sample transfer tube fits through that little space between the vibration head and the plasma arc in the solid model doesn't mean it should really go there...
- ▶ The internal volume of a tube scales with the square of the tube radius, and the amount of care required in keeping it unplugged and running optimally scales with the inverse square of the diameter. Use clean fluids and short runs of very small ID tubing for maximum reliability.



System component electronic integration

In previous sections of this booklet, we described some of the basic building blocks that are used to create fluidic circuits inside OEM equipment. In this section, we will describe some solutions we offer that communicate with and control those blocks so they can be orchestrated into a complete system.

IDEX Health & Science-supplied driver boards and firmware provide flexible control and data acquisition for pumps, valves, sensors and other fluidic components. The instrument developer can easily create coordinated fluidic subsystems from these basic building blocks. These systems can be as simple as a single valve and driver board or as complex as a complete instrument sub-system with multiple pumps, valves, sensors, manifolds, and fluidic connections.

Our controller boards take care of component operation and perform all the regular housekeeping required for reliable operation, so OEM developers can focus their efforts on the overall design challenges relevant to their instrument, rather than the details of implementing specific

communications protocols, or the operation of diverse electromechanical devices.

We also provide demonstration software to get designers using our hardware out-of-the box, and we can then help with optimization of the instrumental procedures and coordination at very early development stages.

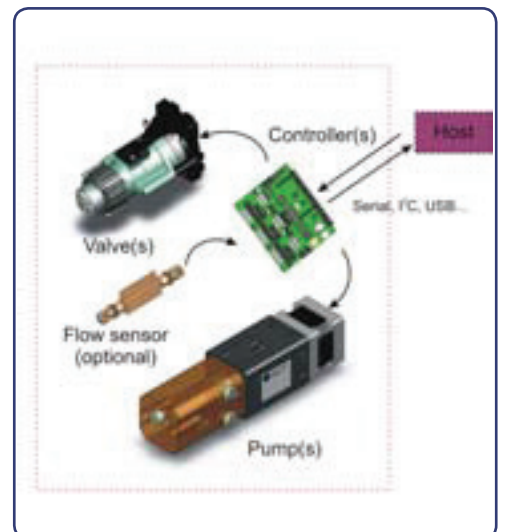
IDEX Health & Science-supplied driver boards are of four general types:

- ▶ Single Motor Drive boards — able to drive one dispensing pump or one rotary valve. These boards also can optionally control two solenoid valves and a pressure sensor or flow sensor
- ▶ Dual Motor Driver boards — able to drive one or two dispensing pumps, one or two rotary valves or a pump and rotary valve in combination. These boards also can optionally control six solenoid valves and a pressure sensor and flow sensor
- ▶ Solenoid Driver boards — able to drive up to 10 solenoid valves. These boards can also optionally control a continuous flow gear pump and a pressure sensor
- ▶ Distribution boards — provides power and control signal distribution to up to 8 of the other boards allowing larger and more complex systems to be controlled from a single interface

With several different control methods to choose from, and several different communication protocols available, there are numerous ways to configure and optimize your hardware, depending on the overall goals of your design. Through partnership with many OEM customers, we have developed a few control topologies that work very well in OEM instrument applications, and we will present them here as starting points for you to consider as you reflect on your instrument layout. If you think a particular design will work well for your application, please contact us for more details.

Our controller boards operate with a common command protocol on any one of 4 industry standard interfaces: USB, RS-232, I2C, and RS-485. The command protocol supports a wealth of useful fluidic operations including:

- ▶ Shear valve positioning — clockwise, counterclockwise and shortest path, multiple flow path configurations
- ▶ Solenoid valve control
- ▶ Aspiration and dispensing of samples coordinated with valve operation
- ▶ Flow feedback pumping — flow rate accurate to 5% on specific fluids
- ▶ Pressure feedback pumping
- ▶ Automated system purging, debubbling, and refilling
- ▶ Pressure, temperature, and flow readout



Example 1: How to run 30 devices simultaneously from one cable

For this design, we were tasked with creating a fluidic platform for the online preparation of aqueous protein samples. The planned instrument was required to aspirate the aqueous samples, hold and process them, then deposit them into vials. Processing steps required adding reagents, applying pressure, and performing chromatography and cleanup procedures in-line. Early stage brainstorming with the customer highlighted several things:

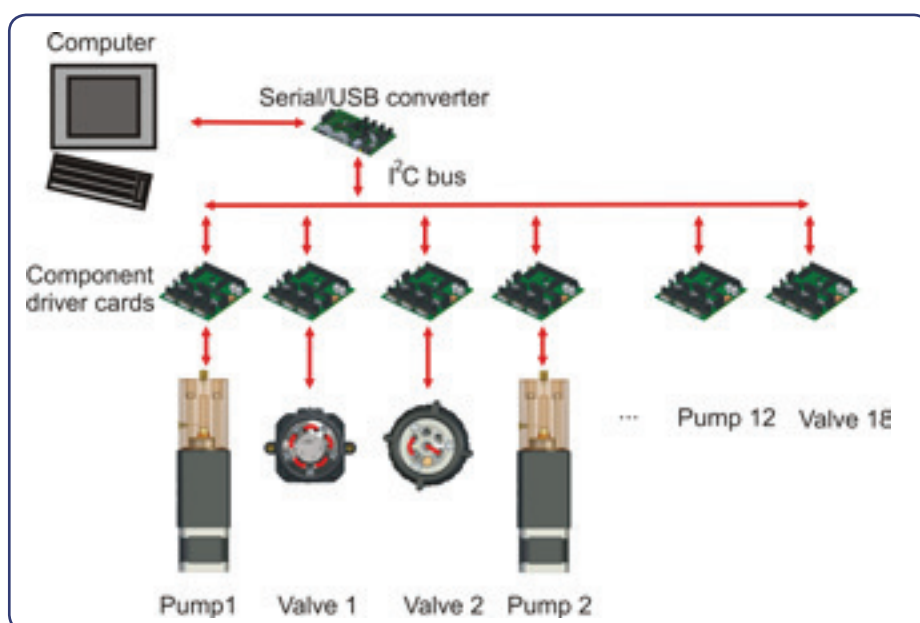
1. Because protein samples are extremely challenging and new protocols were being developed, significant ongoing optimization was required by our OEM partner after delivery of the first platform
2. The customer preferred to optimize their method using a larger set of low-level commands, rather than rely on simplified, high-level commands
3. The system needed to be flexible, so that additional components could be added at will

To achieve the flexibility and configurability required for the application, we decided to utilize an array of individual pumps and valves, with a single master controller (i.e., a host PC) communicating directly with all the individual components. To achieve optimal control of these components (pumps, valves, sensors), we opted to have each component operated from a miniature driver card that had an individualized address.

To achieve individual control from a single communication line to the host PC, we utilized a protocol called I2C. The I2C protocol was implemented on each component driver, and we placed an I2C-to-serial converter between the components and the host. In operation, pumps and valves could be added to the bus without re-designing the control architecture; we simply needed to give the new component a unique address.

Host control of the system was coordinated using our custom evaluation software that allowed sequencing and synchronization based on a time scheduling script. There are several advantages of using this architecture:

1. Individual low-level control of devices is provided directly from the host (this provides maximum flexibility with software control)
2. Devices are individually addressed, and can be added or removed at will
3. Each device contains a controller card that can operate the device autonomously, thus reducing the burden on the common communication line
4. All timing and communication can be directly controlled from the host, so real-time adjustments to system parameters are easily achieved
5. By using a series of small controllers for each device, there is significant flexibility in instrument layout
6. Advanced developers often appreciate the flexibility to operate the components in unconventional (or previously unanticipated) ways. Low-level control functions facilitate this spontaneity



Example 2: smart subsystems working together from a single communications channel

In this example, our customer required a loading system to inject sequential samples from an auto sampler through a flow cell. Due to high-precision requirements, the design also required feedback control over flow rate via an inline flow sensor.

Because of the relatively high level of control demanded at the subassembly level for this instrument, we decided to provide two microcontroller-based subsystems that communicated to the common serial controller interface via high-level commands.

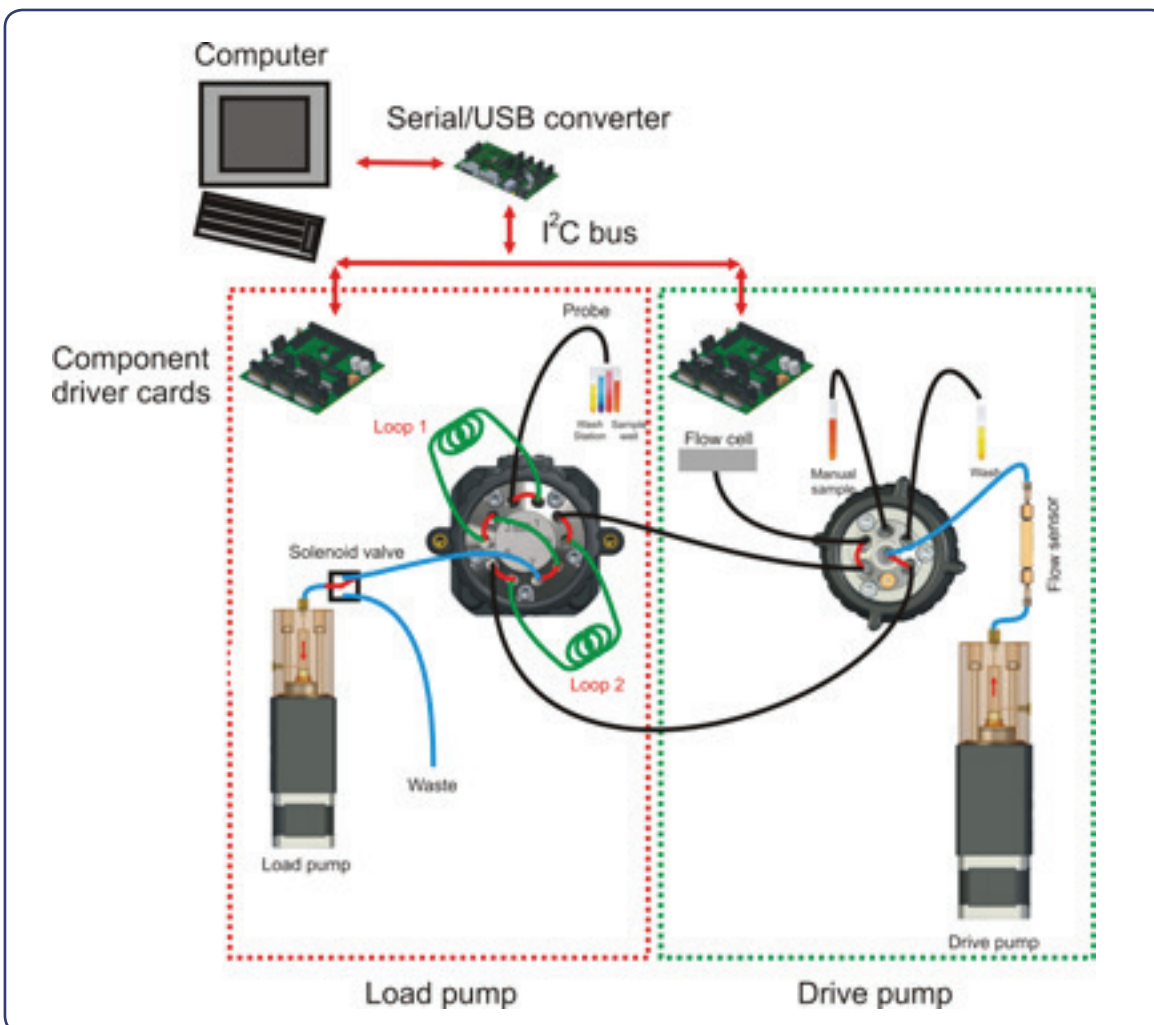
Each pump subassembly controlled a pump, valve, and peripheral devices attached to the driver card.

In this configuration, high-level commands are issued across the I²C bus to each of the two subsystems, and each subsystem contains a variety of individual devices.

The host communication to the I²C converter was via the Universal Serial Bus (USB).

There are several advantages of using this architecture for more complex subsystem functions:

1. Low-level control of individual components is handled by the subsystem controllers, reducing the amount of communications required for control
2. Firmware routines on the subassemblies handle routine tasks, allowing high-level commands to control the devices
3. Many individual subassemblies can be added to the bus, with an individual address for each subassembly
4. Each subassembly can be configured with individual protocols, greatly adding flexibility to the design
5. Simple devices (as shown in Example 1) can be added to the system easily, as they can be added directly to the I²C bus, and share language similarities with our other subsystems

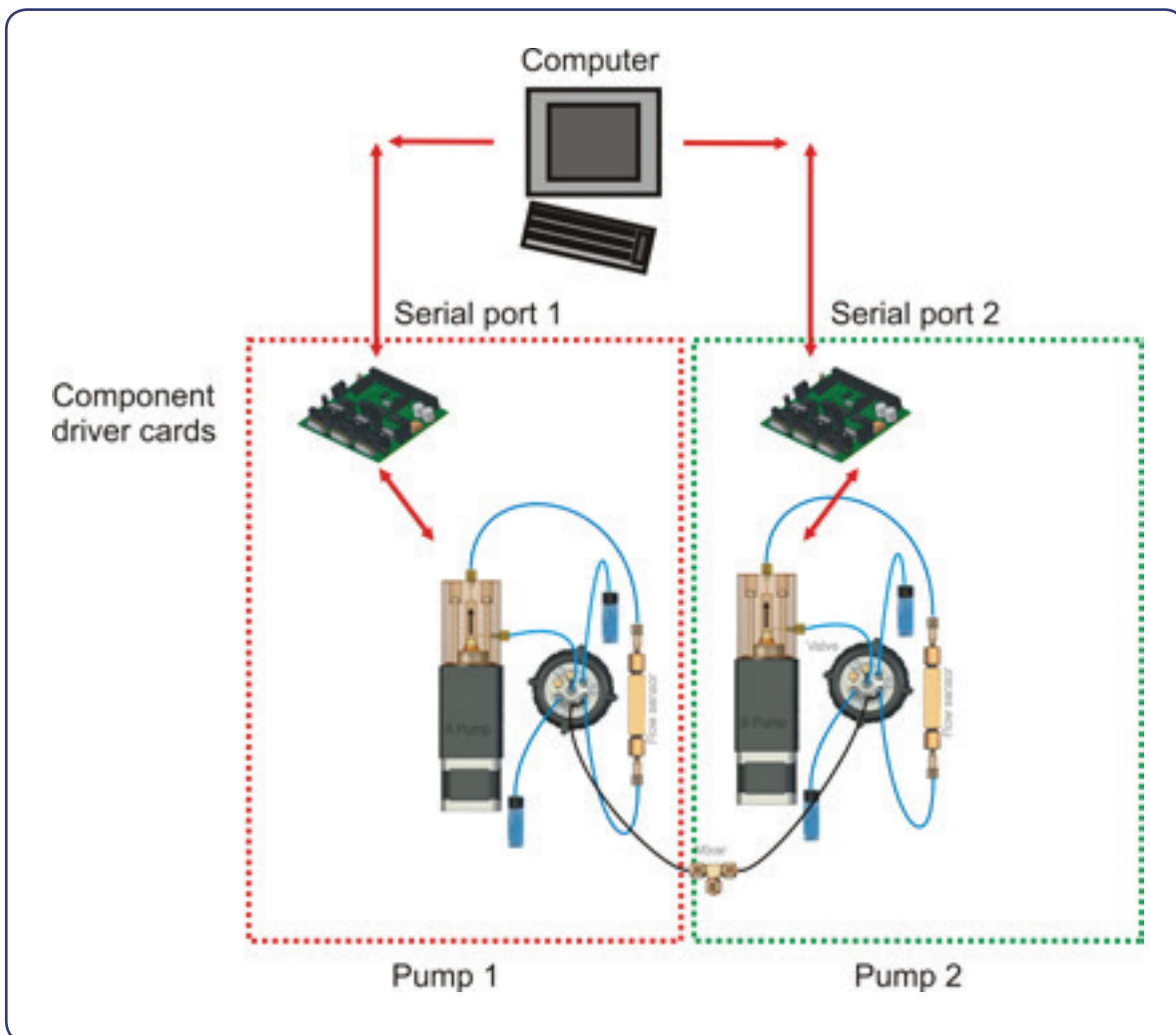


Example 3: multiple serial ports with multiple subsystems

For this application, the customer required control of two subassemblies to create micro gradients for peptide chromatography. Each module was a self-contained and controlled high-pressure pumping system. For this application, the customer required the subassemblies to operate from their legacy serial controller. We opted to have serial protocol directly supported on our subassembly driver cards, and to have each subassembly operate from an individual serial line.

There are several advantages to using this architecture, including:

1. Legacy serial protocols are supported directly, minimizing the re-design required to implement this new system
2. Each device on the system operated from a separate RS-232 line, so parallel command and controls could be facilitated easily across the various ports
3. Low-level control of individual components is handled by the subsystem controllers, reducing the amount of communications required for control
4. Firmware routines on the subassemblies handle routine tasks, allowing high-level commands to control the devices



Some Useful Fluidic Configuration Ideas for Mass Spectrometry



Conventionally, mass spectrometer hardware employed relatively simple reagent flow that was controlled using pressure sources, solenoid valves, multiplexing manifolds, syringe pumps, and other basic fluidic components. Increasing demands for automation and sensitivity in mass spectrometry have driven manufacturers to provide more advanced tuning, calibration, and sample introduction hardware on their machines to facilitate advanced analyses. IDEX Health & Science Mass Spec fluidic systems utilize positive displacement pumps for fluid delivery and rotary shear valves for fluid control. If additional precision is required (e.g., in nanospray applications), addition of pressure-reading capability or flow feedback greatly enhances system performance at extremely low flow rates.



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

All IDEX Health & Science sub-components are integrated under our optimized control architecture, and operate from a 24VDC source. Extreme flexibility is provided during development. Control from the mass spectrometer or host PC is provided through a Serial, I2C, or USB interface, with a full command set provided to the OEM.

Our systems offer several advantages over conventional syringe/pressure/solenoid delivery methods for LC/MS:

- ▶ Lower overall reagent consumption when injecting sample plugs
 - ▶ Less overall reagent-to-reagent carryover than solenoid-based systems
 - ▶ Higher pressure output capability than syringe or solenoid-based systems
 - ▶ Risk of backflow through valves is removed when compared to solenoid solutions
 - ▶ High-pressure shear valves allow the injection of reagents directly into LC column effluent while adding much smaller post-column dead volume than solenoid valves
- ▶ Subsystem firmware optimizes repetitive routine tasks (e.g., washing, rinsing, or injecting sample plugs into LC effluent)
 - ▶ Positive displacement fluid system is tolerant of changes in downstream pressure at source when compared to pressure-driven systems
 - ▶ Ultra-hard piston and dynamic pump seal provide greatly improved lifetime over syringe-based pumping solutions (up to several million actuations)

We have provided some good ideas in the next section for you to review as you consider designing a new fluidic system for your instrument. It is hoped that these diagrams provide information and inspiration for your design, and that you will contact us for more details if you feel inspired.

We advise the instrument developer to assess the Intellectual Property around their design prior to development to ensure that no conflicts arise. The ideas presented in this booklet are intended to be starting points for discussion, and no particular applicability, ownership, or reliability is guaranteed for any given application.

SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

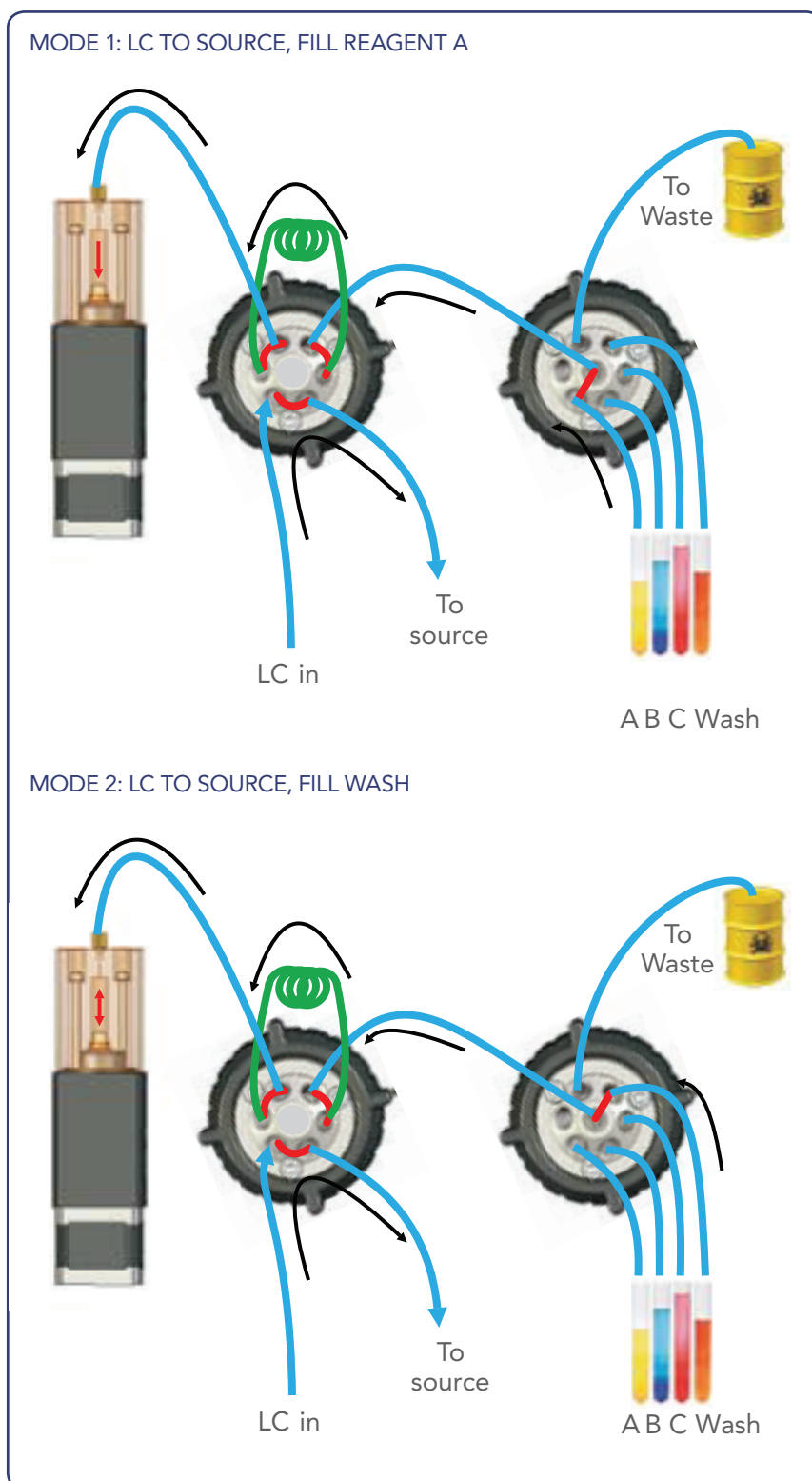
Idea 1 — Injection of sample into flowing LC effluent—fixed loop

This idea is a single-pump, two-valve configuration that allows for the injection of multiple different analytes into the flowing LC stream before introduction to a MS source. Some OEMs require manual addition of user-specified reagents or samples, this addition can be accomplished by aspirating from a vial in positions RA, RB, RC, or Wash. This example shows a wash solution in position 4, to facilitate rinsing the loop system between samples.

Additional reagents can be added by using a 10/11 (or higher number) selector valve. IDEX Health & Science can help you decide on tubing diameters, lengths, loop sizes, and pump sizes to minimize carryover and sample waste, depending on your sample size and flow rate range.

This two-valve configuration has the advantage that filling, flushing, and purging the system with new reagents can be performed without interrupting the flow of LC effluent to the MS source. Because both flow streams are combined before introduction to the source, addition of reagents is accomplished simultaneously with LC analysis through a single electrospray needle.

The displacement pump and shear valve combination shown will operate to high pressures, so is relatively immune to changes in outlet pressure seen as the source ages. Because of the high-pressure capability of most of our pumps and valves, online desalting could be employed using this scheme and a packed tip.



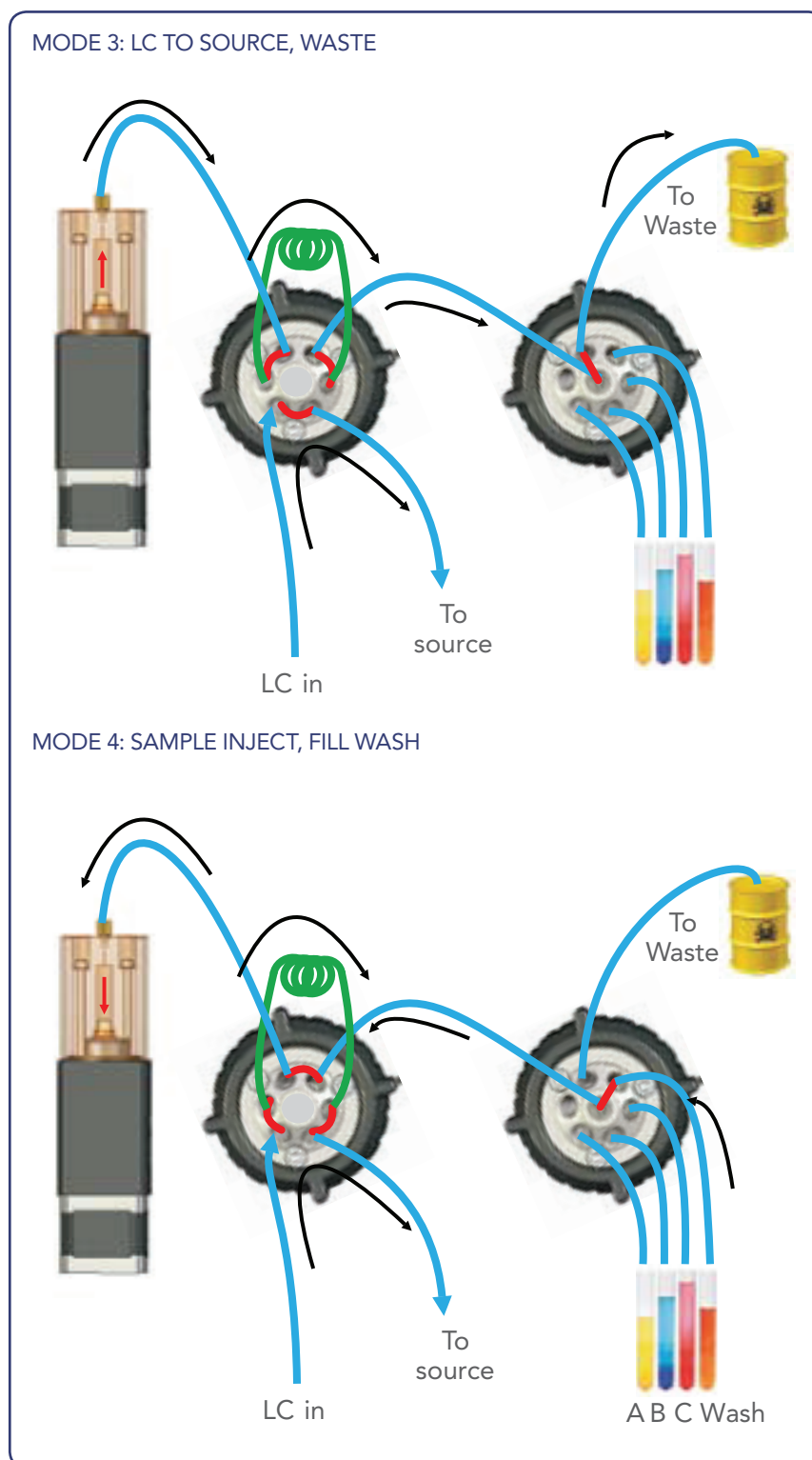
SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

For optimal operation, we recommend that you properly ground the transfer line between the valve and the source. Minimum internal volume and short lengths are desirable in the transfer line, to prevent bandbroadening, lengthy delay times, or adsorption of sample. For the analysis of phosphopeptides or other metal-sensitive analytes, we can offer non-metallic or specialized flow paths for this system.

All operational modes are supported internally via IDEX Health & Science controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided for evaluation purposes. This subsystem can be configured to run from any of the control schemes described in the System Control section earlier.

We have utilized modified versions of this system successfully for injecting plugs into flowing streams in related diagnostic and analytical markets.

Complete tubing/fitting kits are created within IDEX Health & Science to support this design.



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

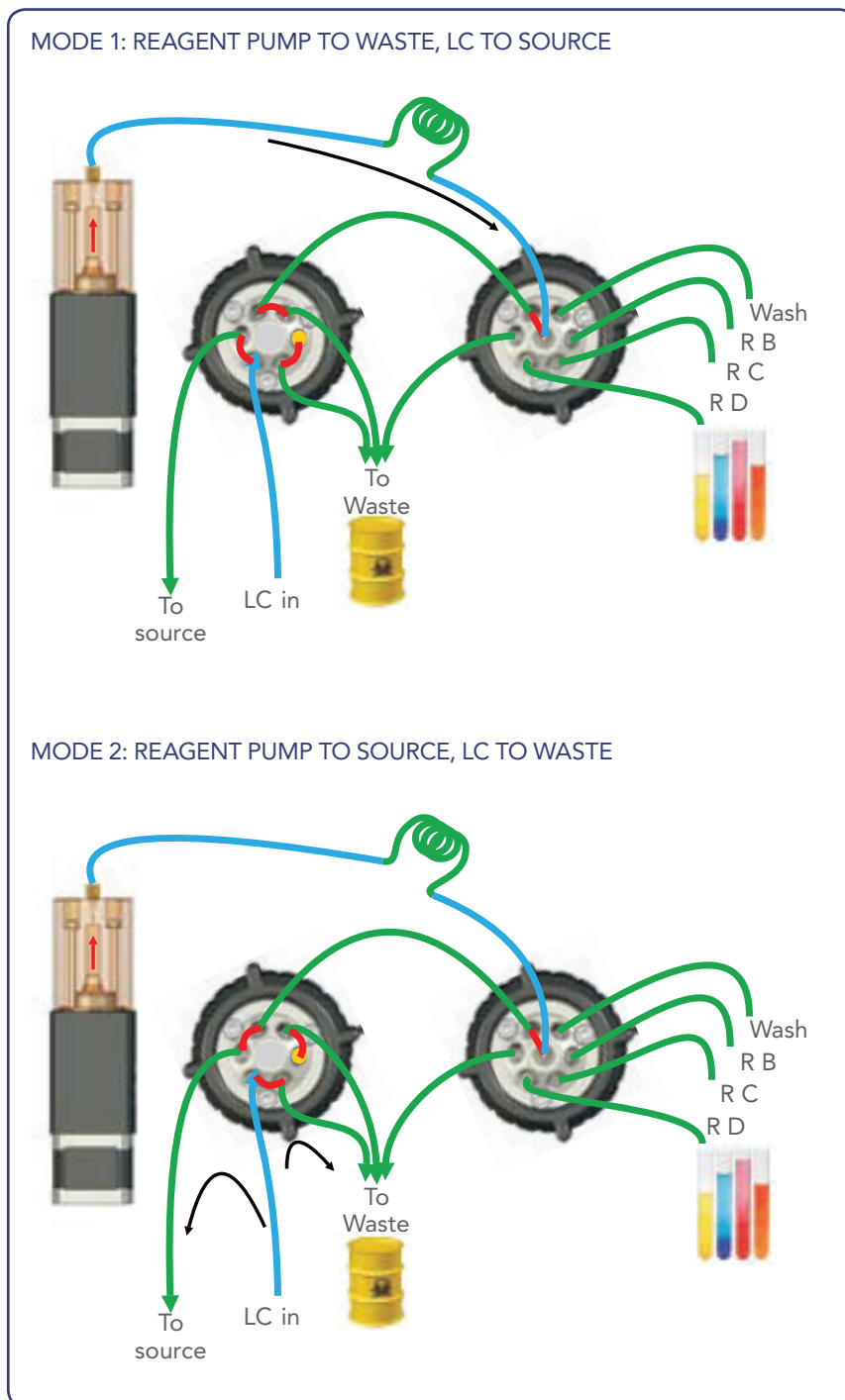
Idea 2 — Injection of sample into flowing LC effluent-variable injection volume

This idea is a single-pump, two-valve configuration that allows for the injection of multiple analytes into the flowing LC stream before introduction to a MS source. This system differs from Idea 1 in that instead of a fixed-volume sample loop, the method uses a delay line before the pump to hold sample, allowing injections of varying length to be introduced. Some OEMs require manual addition of user-specified reagents or samples, this addition can be accomplished by aspirating from a vial in positions RA, RB, RC, or Wash. This example shows a wash solution in position 4, to facilitate rinsing the loop system between samples.

Additional reagents can be added by using a 10/11 (or higher number) selector valve. IDEX Health & Science can help you decide on tubing diameters, lengths, loop sizes, and pump sizes to minimize carryover and sample waste, depending on your sample size and flow rate range.

This two-valve configuration has the advantage that filling, flushing, and purging the system with new reagents can be performed without interrupting the flow of LC effluent to the MS source. Because both flow streams are combined before introduction to the source, addition of reagents is accomplished simultaneously with LC analysis through a single electrospray needle.

The displacement pump and shear valve combination shown will operate to high pressures, so it is relatively immune to changes in outlet pressure seen as the source ages. Because of the high pressure capability of most of our pumps and valves, online desalting could be employed using this scheme and a packed tip.



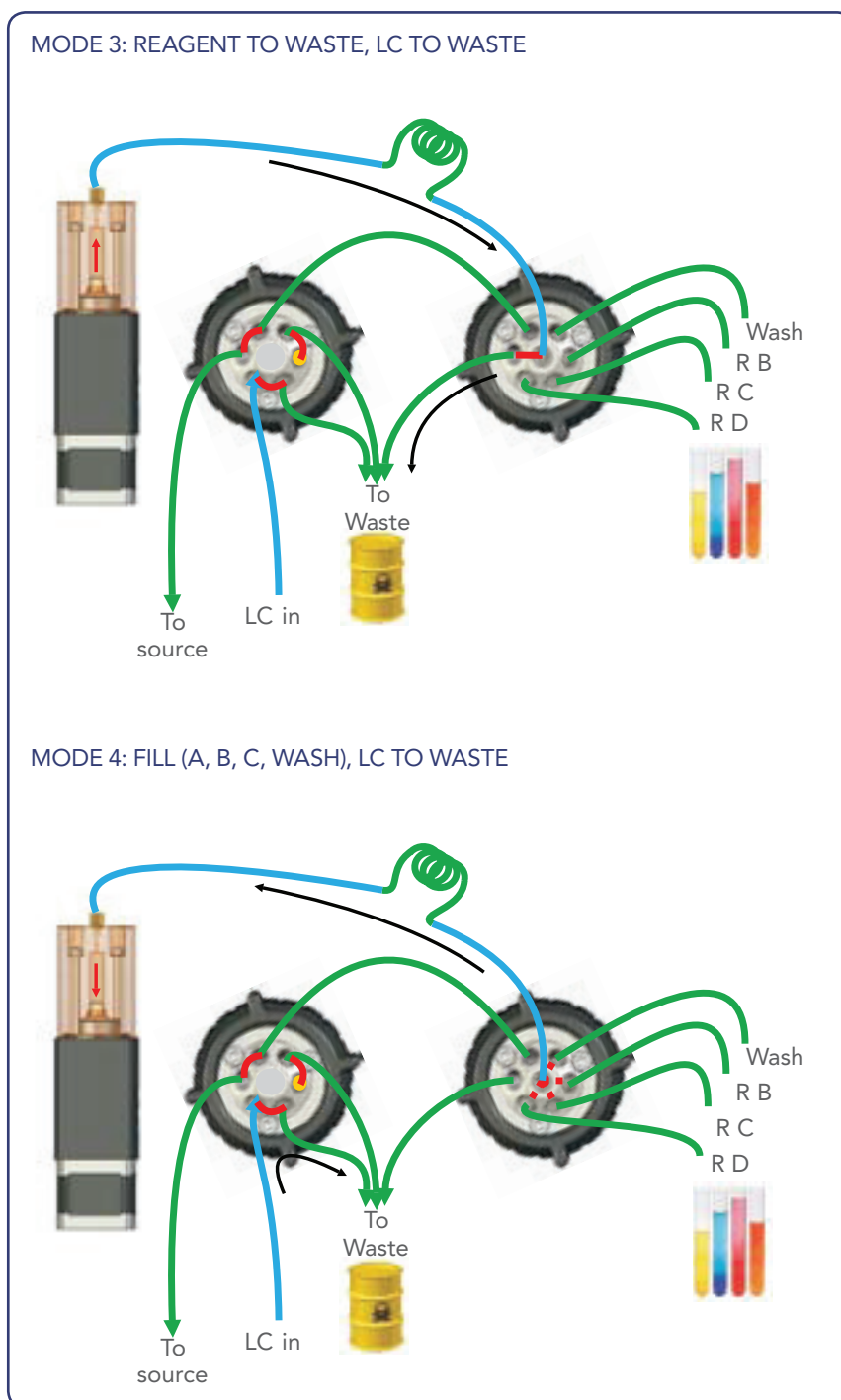
SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

For optimal operation, we recommend that you properly ground the transfer line between the valve and the source. Minimum internal volume and short lengths are desirable in the transfer line, to prevent bandbroadening, lengthy delay times, or adsorption of sample. For the analysis of phosphopeptides or other metal-sensitive analytes, we can offer non-metallic or specialized flow paths for this system.

All operational modes are supported internally via IDEX controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided for evaluation purposes. This subsystem can be configured to run from any of the control schemes described in the System Control section earlier.

We have utilized modified versions of this system successfully for injecting plugs into flowing streams in related diagnostic and analytical markets.

Complete tubing/fitting kits are created within IDEX Health & Science to support this design.



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

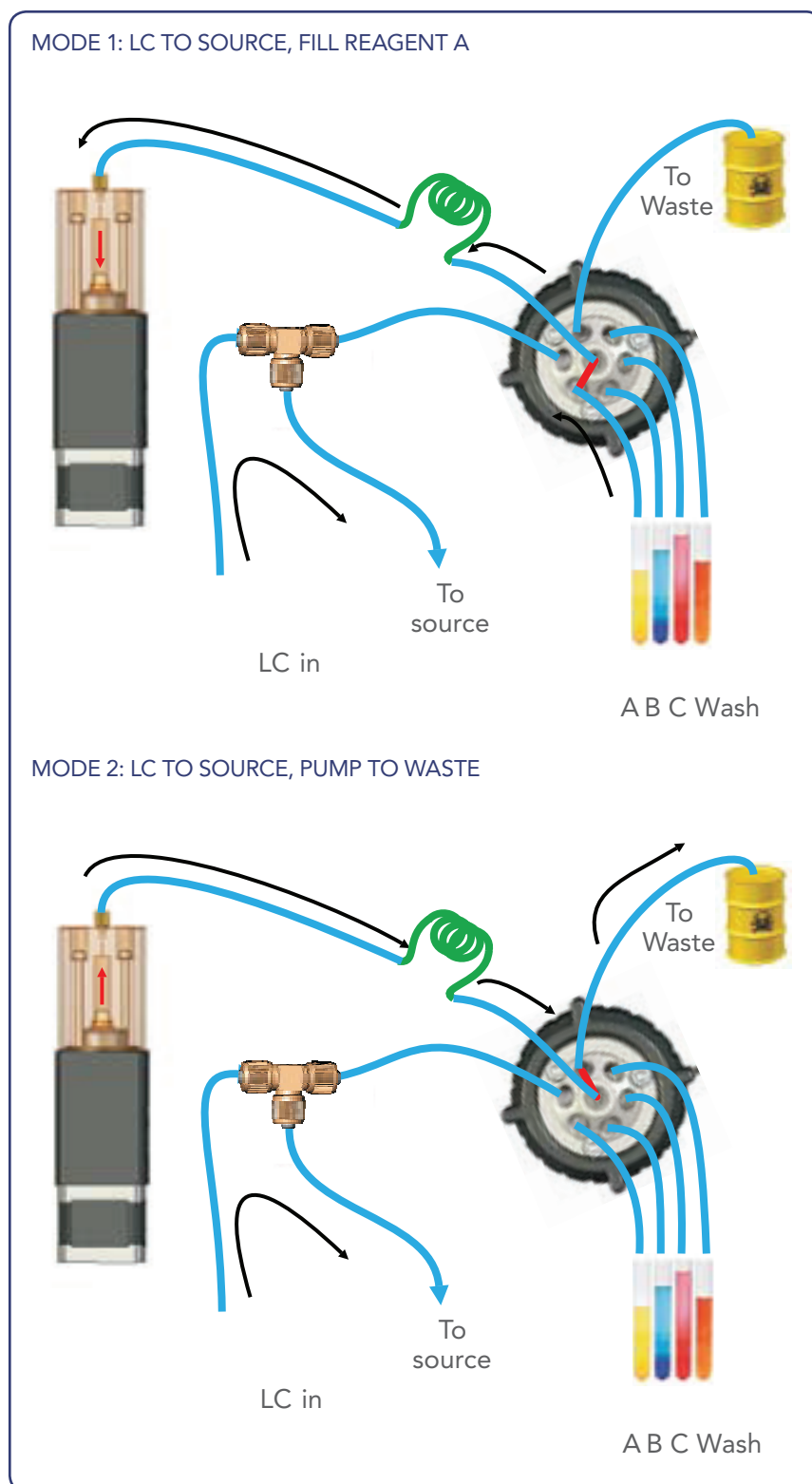
Idea 3 — Merging of sample into flowing LC effluent

This idea is for the mixing of LC effluent and an internal standard (or other post-column dilution reagent) prior to introduction to the MS source. It differs from Idea 1 in that the reagent is added to the flowing effluent in real time using a mixing tee, so doesn't require the timed injection of plugs into the stream. The configuration is also useful for online dilution of salty samples to assist in electrospray.

One big advantage of this system over the one shown in Idea 1, is that interruption of the flow is not required, and if flows are adjusted correctly, post-column bandbroadening can be greatly minimized. Some OEMs require manual addition of user-specified reagents or samples, this addition can be accomplished by aspirating from a vial in positions RA, RB, RC, or RD. This example shows a wash solution in position 4, to facilitate rinsing the loop system between samples.

Additional reagents can be added by using a 10/11 (or higher number) selector valve. IDEX Health & Science can help you decide on tubing diameters, lengths, loop sizes, and pump sizes to minimize carryover and sample waste, depending on your sample size and flow rate range.

This configuration has the advantage that filling, flushing, and purging the system with new reagents can be performed without interrupting the flow of LC effluent to the MS source. Although the flow rate during reagent addition will be higher than the flow rate of the LC alone. Because both flow streams are combined before introduction to the source, addition of reagents is accomplished simultaneously with LC analysis through a single electrospray needle.



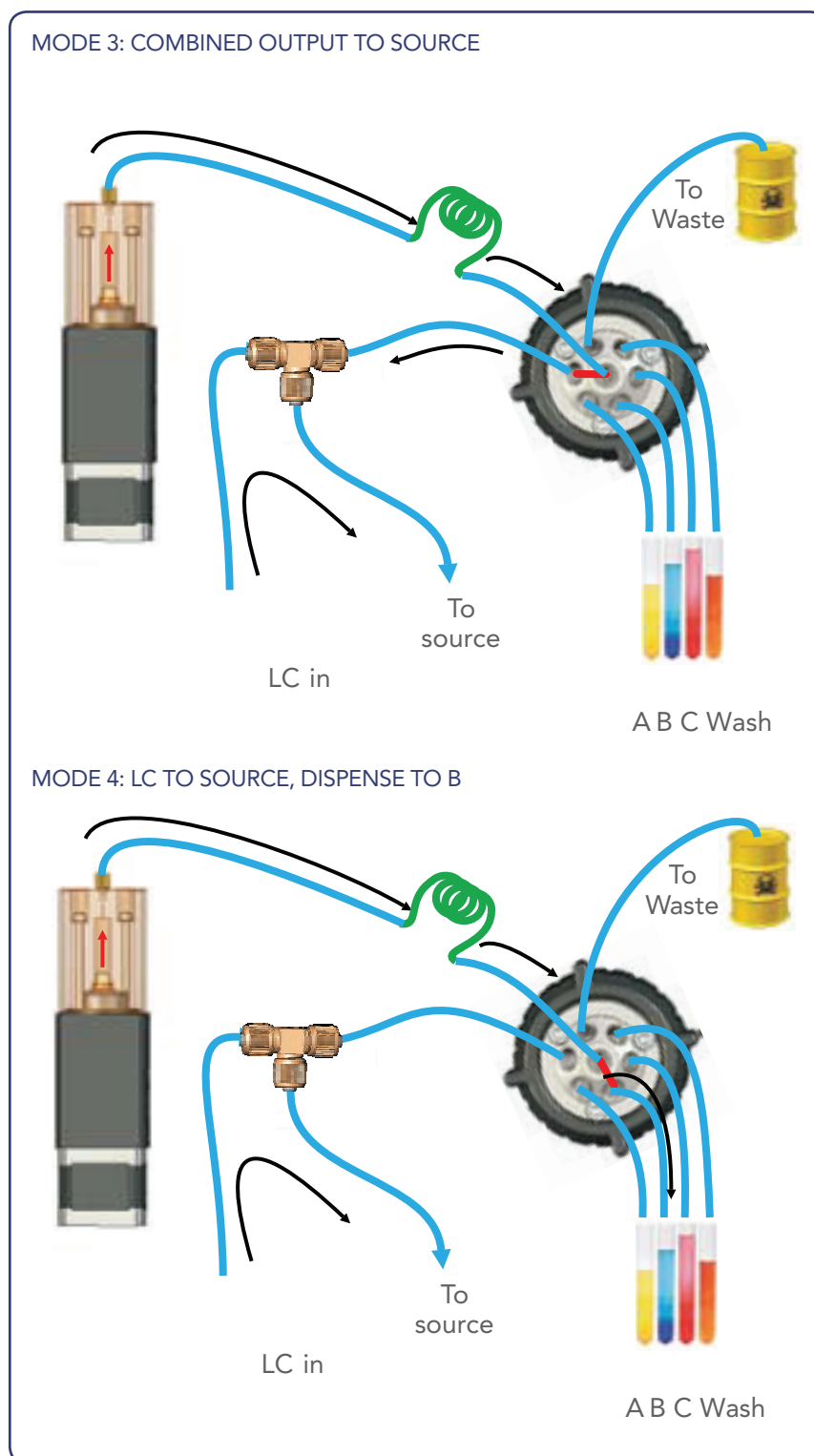
SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

The displacement pump and shear valve combination shown will operate to high pressures, and so the system is relatively immune to changes in outlet pressure seen as the source ages or plugs. Because of the high pressure capability of most of our pumps and valves, online desalting could be employed using this scheme and a packed tip.

For optimal operation, we recommend that you properly ground the transfer line between the valve and the source. Minimum internal volume and short lengths are desirable in the transfer line, to prevent bandbroadening, lengthy delay times, or adsorption of sample. For the analysis of phosphopeptides or other metal-sensitive analytes, we can offer non-metallic or specialized flow paths for this system.

All operational modes are supported internally via IDEX Health & Science controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided for evaluation purposes. This subsystem can be configured to run from any of the control schemes described in the System Control section earlier.

Complete tubing/fitting kits are created within IDEX Health & Science to support this design.



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

Idea 4 — A highly precise pumping source for nanospray

This idea is a single-pump, single-valve configuration that incorporates a flow sensor in the output flow path. This flow sensor reports the actual output flow rate to the pump's internal driver card, and that driver dynamically maintains the output flow rate in real time by adjusting the pump velocity. This feedback ensures stable, precise flow is achieved, even at very low flow rates, or under conditions of changing source pressure.

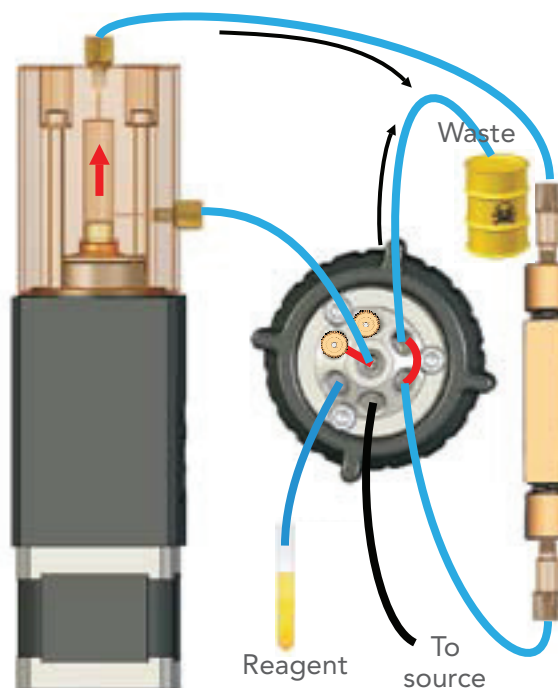
This application is based on our CDM flow feedback pumping system, and information about the CDM is available on our webpage.

This configuration is particularly useful for application to nanospray sources, where stable nanospray must be achieved under diverse pressure regimes. Alternatively, we have utilized the system to push sample for direct infusion under nanospray conditions. The best examples of this system for direct sample analyses use a separate injection loop to hold the sample downstream of this pump.

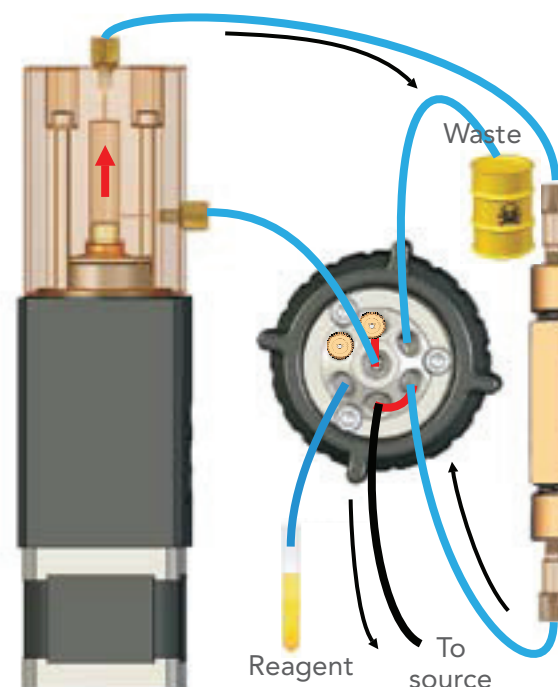
The displacement pump and shear valve combination shown will operate to high pressures, and so the system is relatively immune to changes in outlet pressure seen as the source ages or plugs. Because of the high pressure capability of most of our pumps and valves, online desalting could be employed using this scheme and a packed tip.

For optimal operation, we recommend that you properly ground the transfer line between the valve and the source. Minimum internal volume and short lengths are desirable in the transfer line, to prevent lengthy delay times or adsorption of sample. For the analysis of phosphopeptides or other metal-sensitive analytes, we can offer non-metallic or specialized flow paths for this system.

MODE 1: REAGENT TO WASTE



MODE 2: REAGENT TO SOURCE

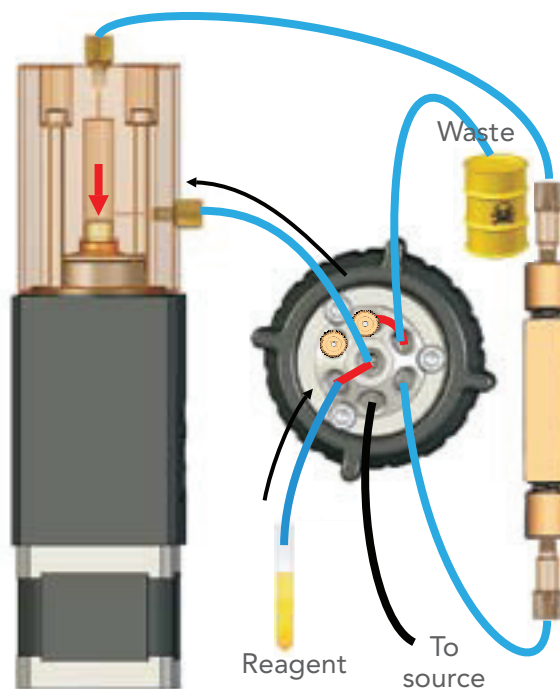


SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

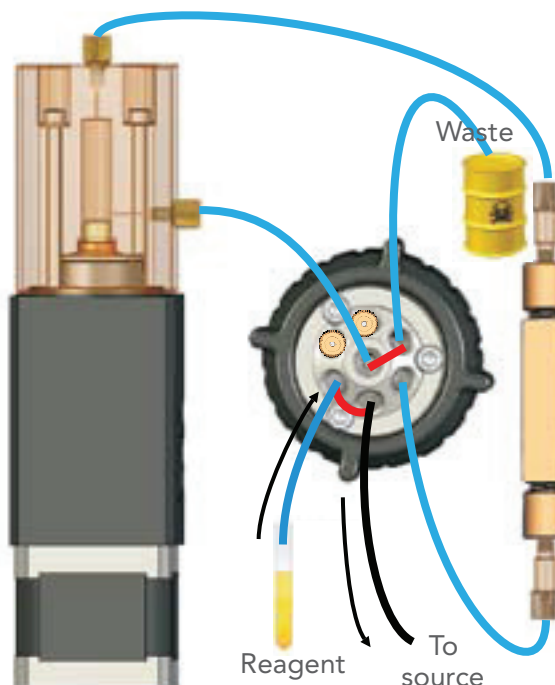
All operational modes are supported internally via IDEX Health & Science controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided for evaluation purposes. This subsystem can be configured to run from any of the control schemes described in the System Control section earlier.

Complete tubing/fitting kits are created within IDEX Health & Science to support this design.

MODE 3: FILL REAGENT



MODE 4: MANUAL REAGENT (UNUSED)



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

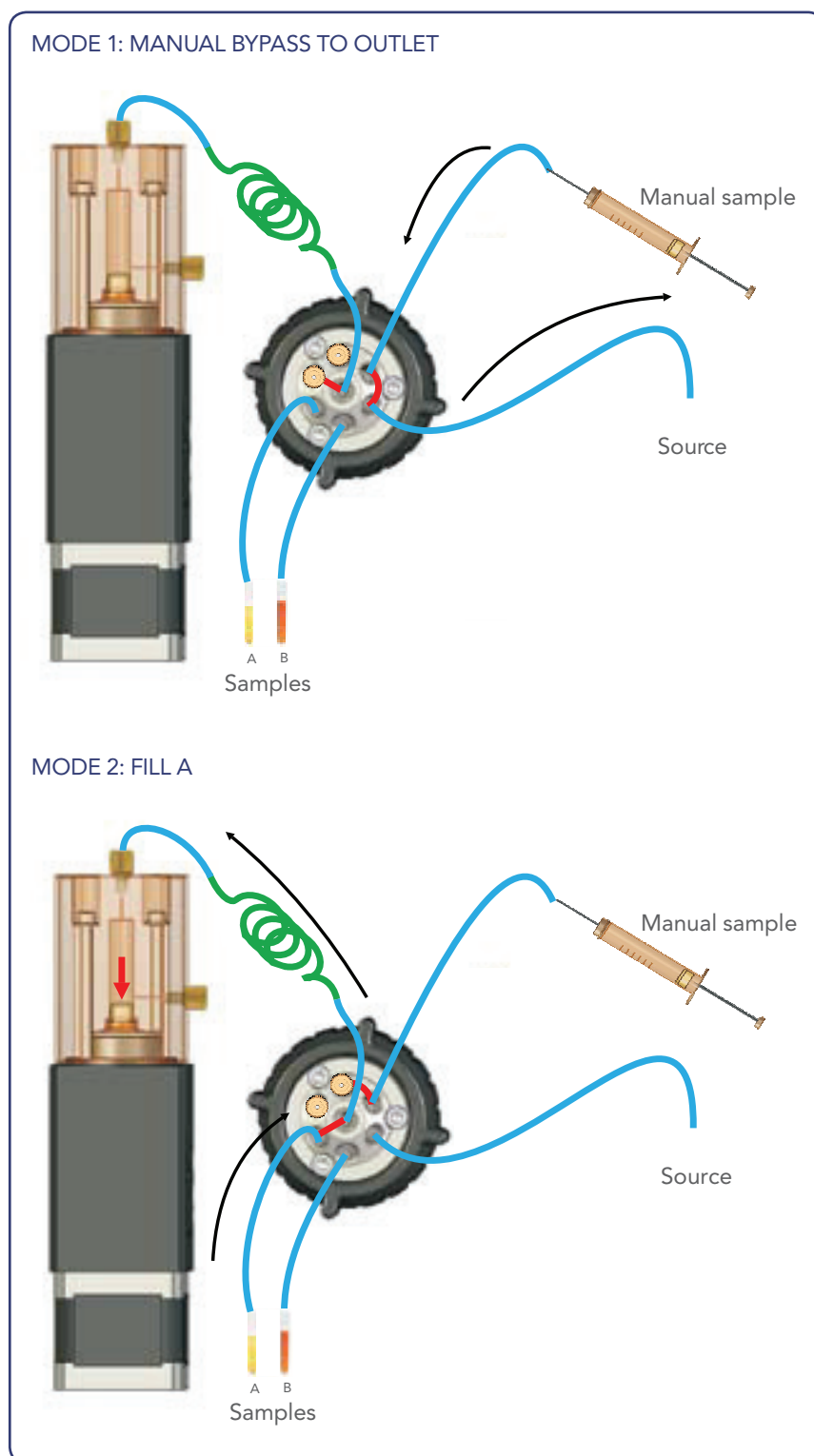
Idea 5 — Two reagents and manual sample infusion to source

This idea is a single-pump, single-valve configuration that lets the user either inject samples or wash the pump from sample vials A and B, or alternatively manually infuse samples directly from a syringe drive or other pressurized vessel. It is a good example of the use of a unique valve rotor pattern to achieve an unconventional task.

The loop size and pump volume need to be optimized for a given configuration so that carryover and reagent usage are minimized.

The displacement pump and shear valve combination shown will operate to high pressures, and so the system is relatively immune to changes in outlet pressure seen as the source ages or plugs. Because of the high-pressure capability of most of our pumps and valves, online desalting could be employed using this scheme and a packed tip.

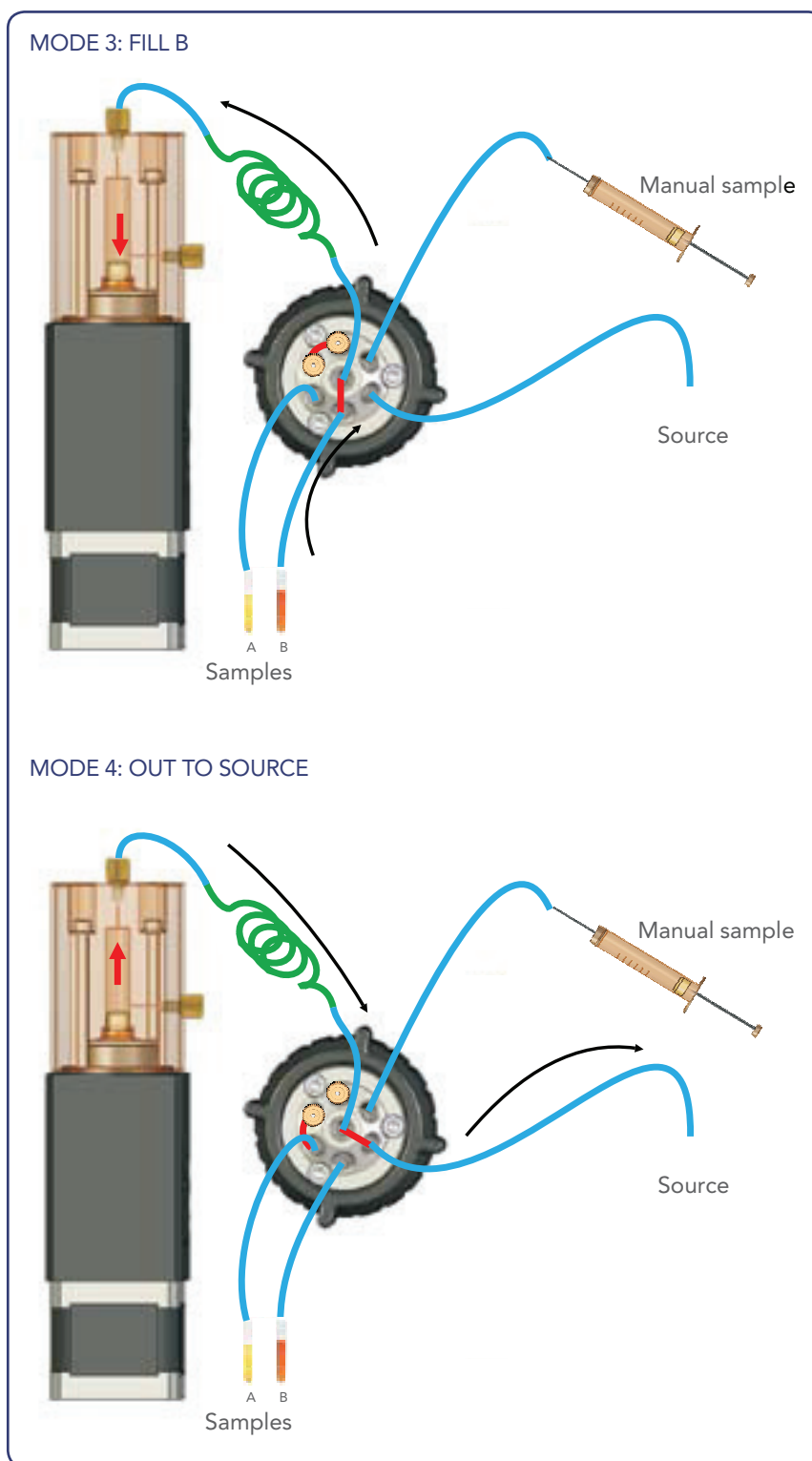
For optimal operation, we recommend that you properly ground the transfer line between the valve and the source. Minimum internal volume and short lengths are desirable in the transfer line, to prevent lengthy delay times or adsorption of sample. For the analysis of phosphopeptides or other metal-sensitive analytes, we can offer non-metallic or specialized flow paths for this system.



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

All operational modes are supported internally via IDEX Health & Science controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided for evaluation purposes. This subsystem can be configured to run from any of the control schemes described in the System Control section earlier.

Complete tubing/fitting kits are created within IDEX Health & Science to support this design.



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

Idea 6 — Two injection loops with an autosampler — pseudo-continuous sampling

This idea is for injecting samples into a flow cell, MS source, or other device from an autosampler using two injection loops. This is a good example of the high level of integration and sophistication we can do when required for an application.

If you follow the fluid path arrows in the diagram, you will observe that we are using a load pump to aspirate samples into one of two sample loops. While one loop is loading, the other is being emptied to the outlet by a drive pump. External solenoid valves control the emptying of the load pump.

As an alternative to the load pump, we could use a peristaltic or other low-pressure pump.

One key advantage of utilizing an autosampler platform for sample introduction is that it allows a great deal of extra capability on the valve fluidics because the ports are not tied up with multiplexing samples.

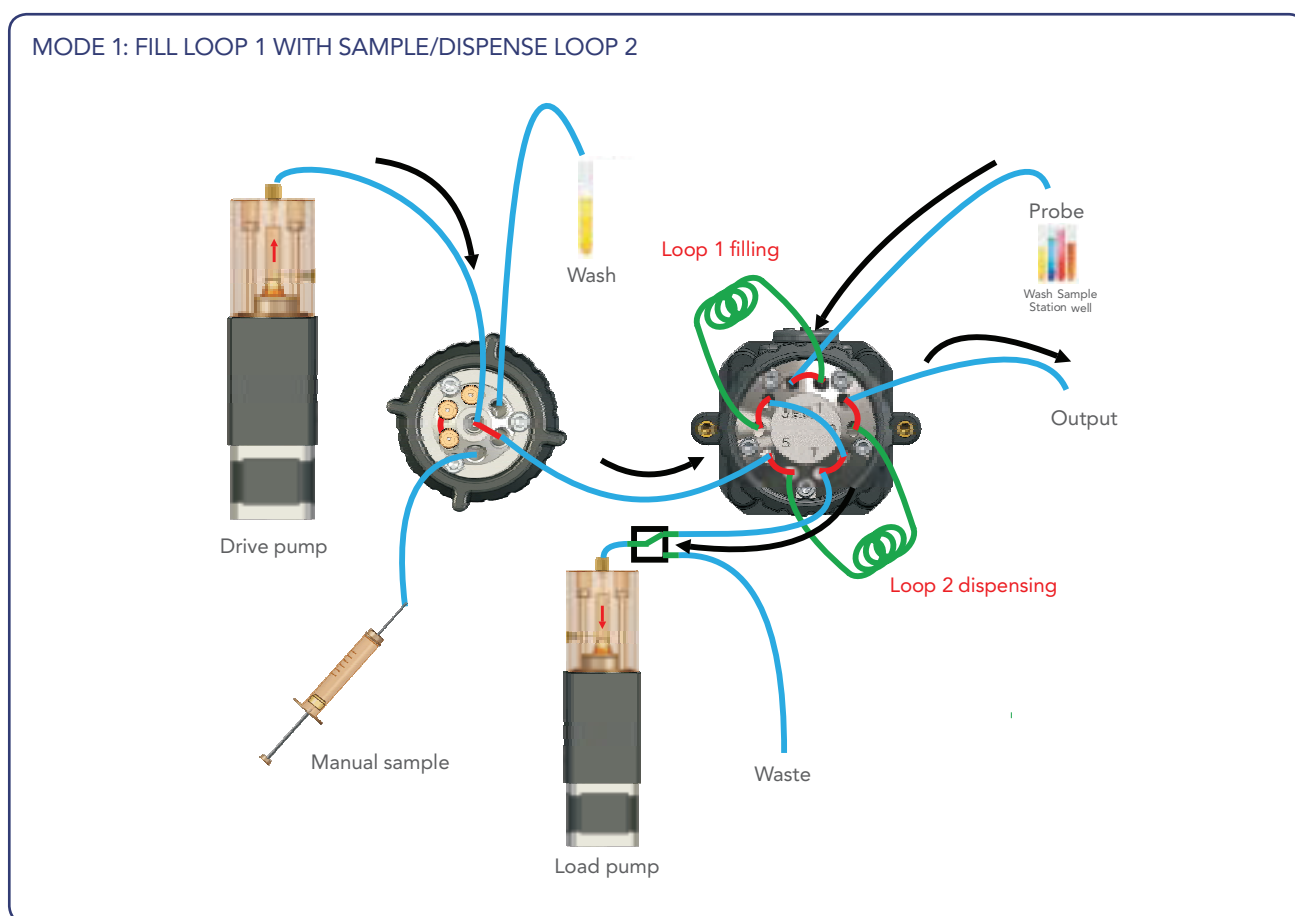
The displacement pump and shear valve combination shown will operate to high pressures, and so the system is relatively immune to changes in outlet pressure seen as the source ages or plugs. Because of the high pressure capability of most of our pumps and valves, online desalting could be employed using this scheme and a packed tip.

For optimal operation, we recommend that you properly ground the transfer line between the valve and the source. Minimum internal volume and short lengths are desirable in the transfer line, to prevent bandbroadening,

lengthy delay times, or adsorption of sample. For the analysis of phosphopeptides or other metal-sensitive analytes, we can offer non-metallic or specialized flow paths for this system.

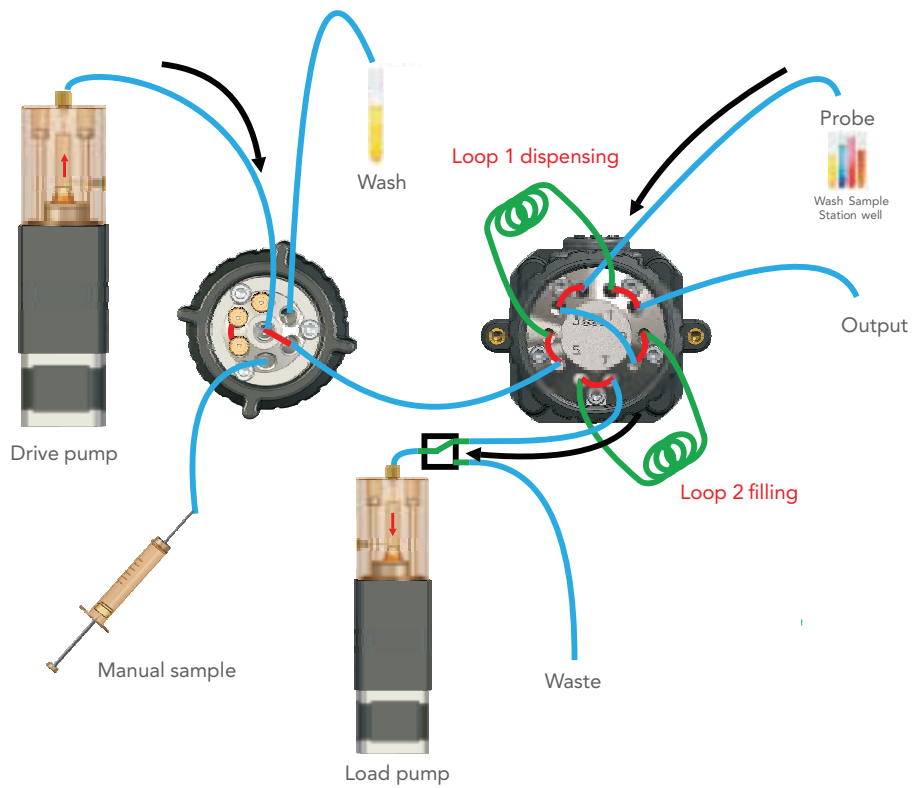
All operational modes are supported internally via IDEX Health & Science controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided for evaluation purposes. This subsystem can be configured to run from any of the control schemes described in the System Control section earlier.

Complete tubing/fitting kits are created within IDEX Health & Science to support this design.

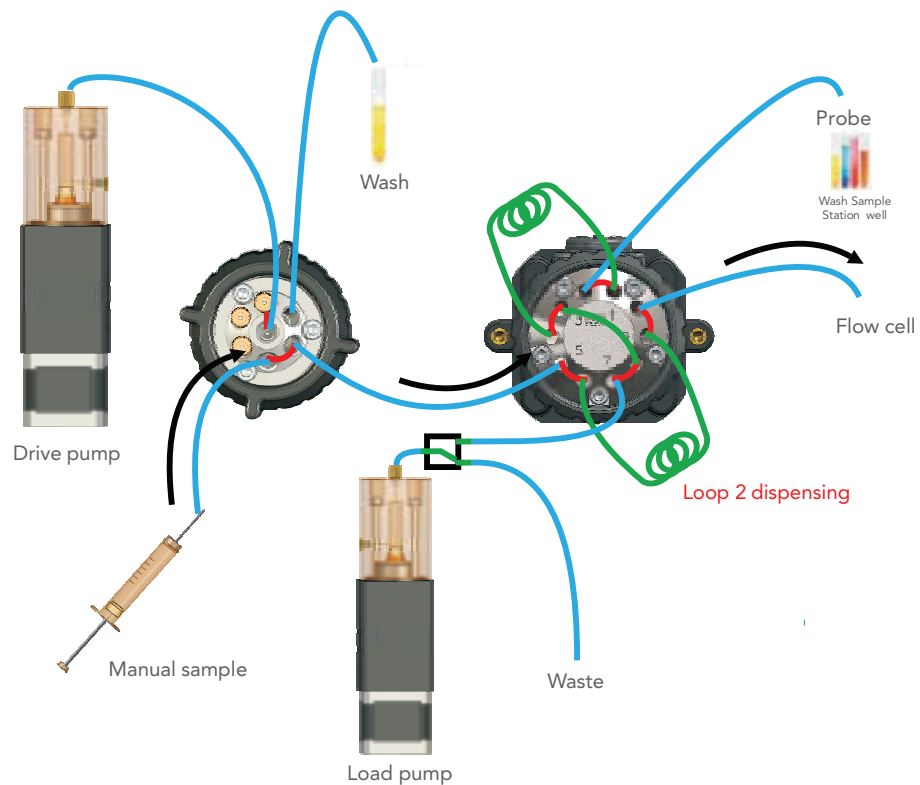


SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

MODE 2: FILL LOOP 2 WITH SAMPLE/DISPENSE LOOP 1

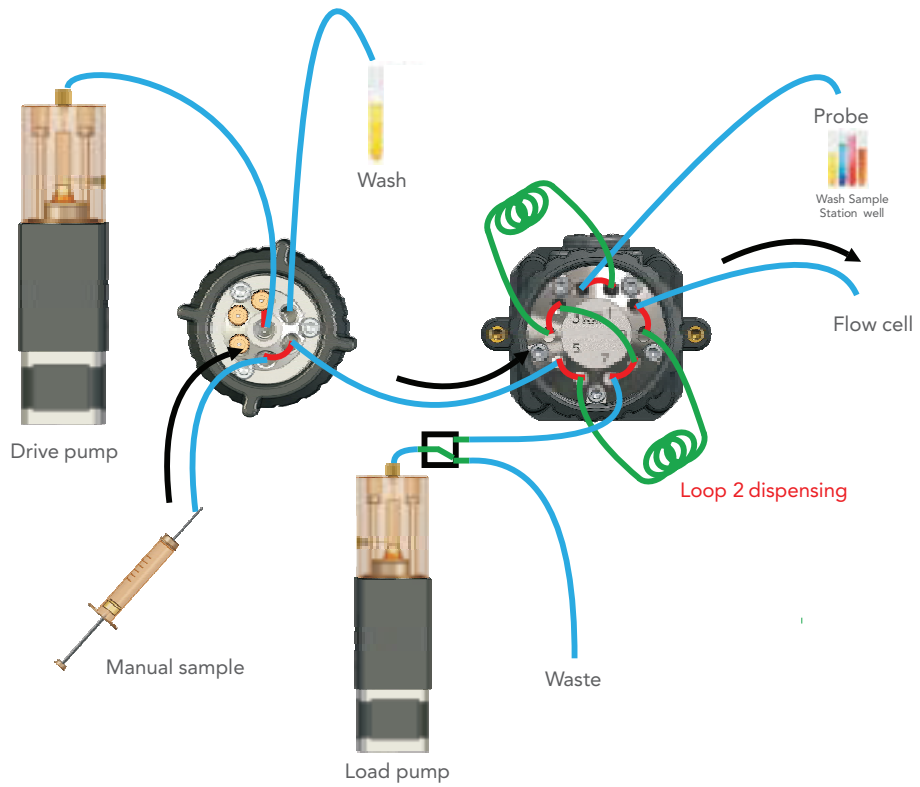


MODE 3: EMPTY LOAD PUMP TO WASTE

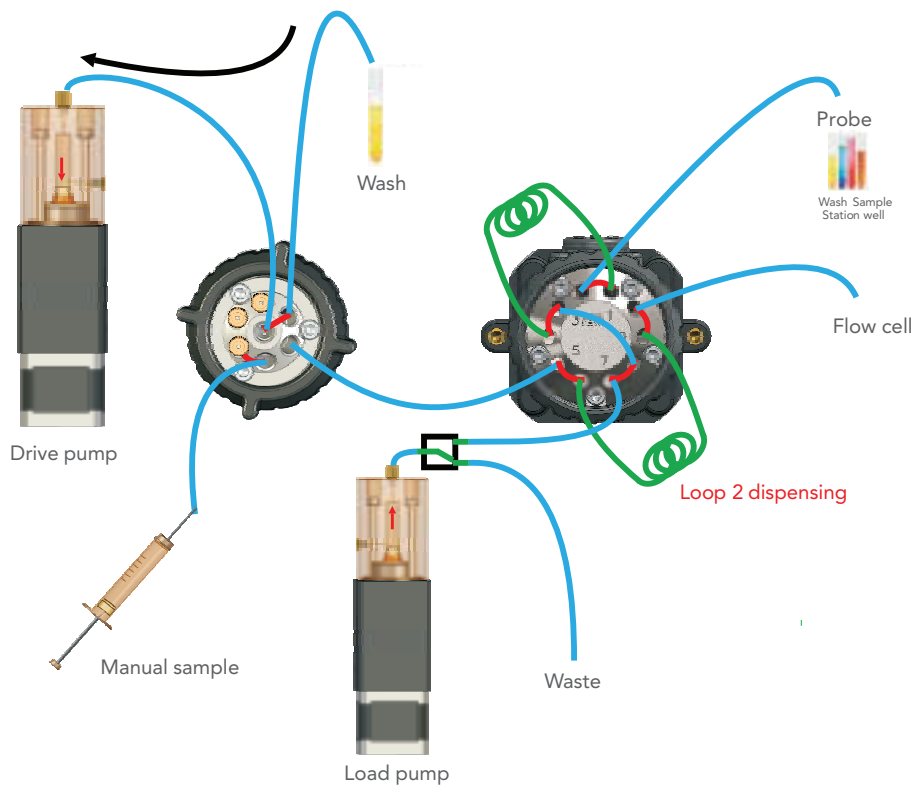


SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

MODE 4: MANUAL SAMPLE



MODE 5: FILL DRIVE PUMP



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

Idea 7 — Two injection loops with an autosampler — Peristaltic Drive pump

This idea is for injecting samples into a flow cell, MS source, or other device from an autosampler using two injection loops. Think of this idea as the same as Idea 6, but using a flow-feedback peristaltic pump for driving the fluid, instead of a piston pump. This is a good example of the high level of integration and sophistication we can do when required for an application.

If you follow the fluid path arrows in the diagram, you will observe that we are using a load pump to aspirate samples into one of two sample loops. While one loop is loading, the other is being emptied to the outlet by a drive pump.

External solenoid valves control the emptying of the load pump.

As an alternative to the load pump, we could use a peristaltic or other low-pressure pump.

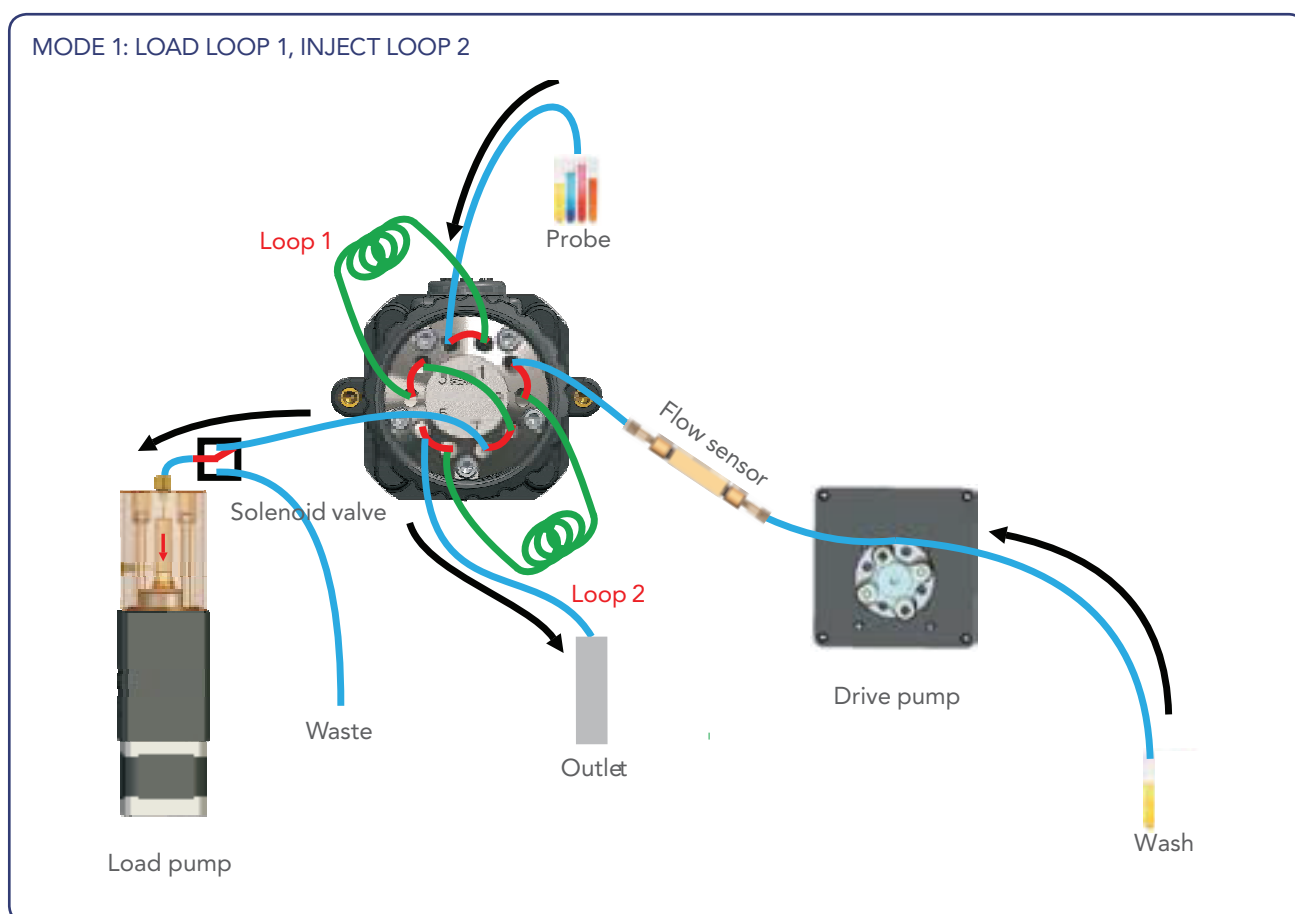
One key advantage of utilizing an autosampler platform for sample introduction is that it allows a great deal of extra capability on the valve fluidics because the ports are not tied up with multiplexing samples.

For optimal operation, we recommend that you properly ground the transfer line between the valve and the source. Minimum internal volume and short lengths are desirable in the transfer line, to prevent bandbroadening, lengthy delay times, or adsorption of sample. For the analysis of

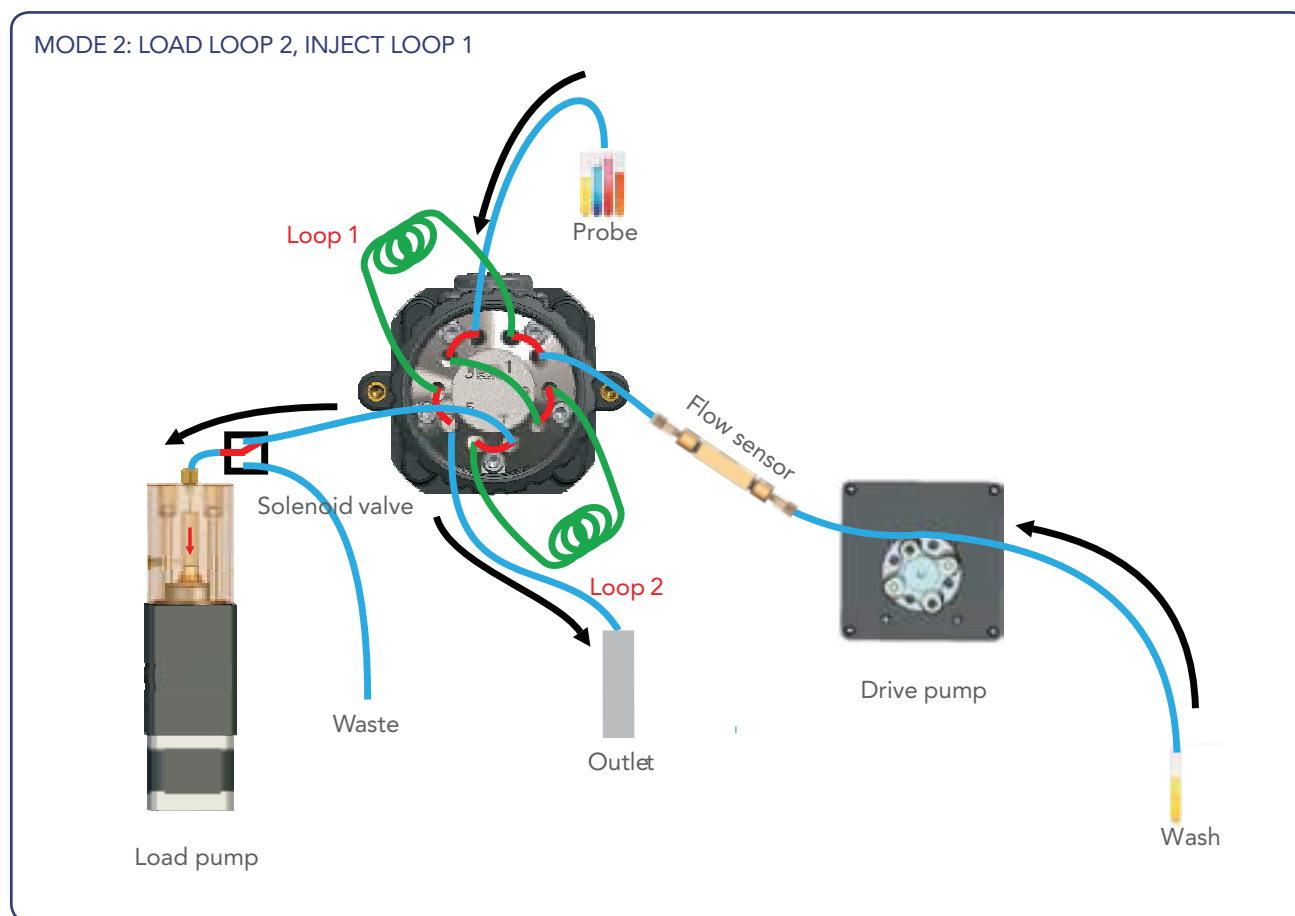
phosphopeptides or other metal-sensitive analytes, we can offer non-metallic or specialized flow paths for this system.

All operational modes are supported internally via IDEX Health & Science controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided for evaluation purposes. This subsystem can be configured to run from any of the control schemes described in the System Control section earlier.

Complete tubing/fitting kits are created within IDEX Health & Science to support this design.



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

Idea 8 — Nano gradient chromatography

This idea is for the generation of nano chromatography gradients. The fluid paths shown in the diagrams are two of our flow feedback CDM modules with their outputs tied together through a mixing tee, then onto a 10-port injection valve. An autosampler provides samples to the injection valve, and a column is attached downstream.

For this configuration, we normally use strong organic solvents in the B pump, and aqueous phase in the A pumps, then the output of each CDM is combined to provide splitless nano gradients with flow sensor feedback control. We have achieved very high run-to-run reproducibility with this configuration.

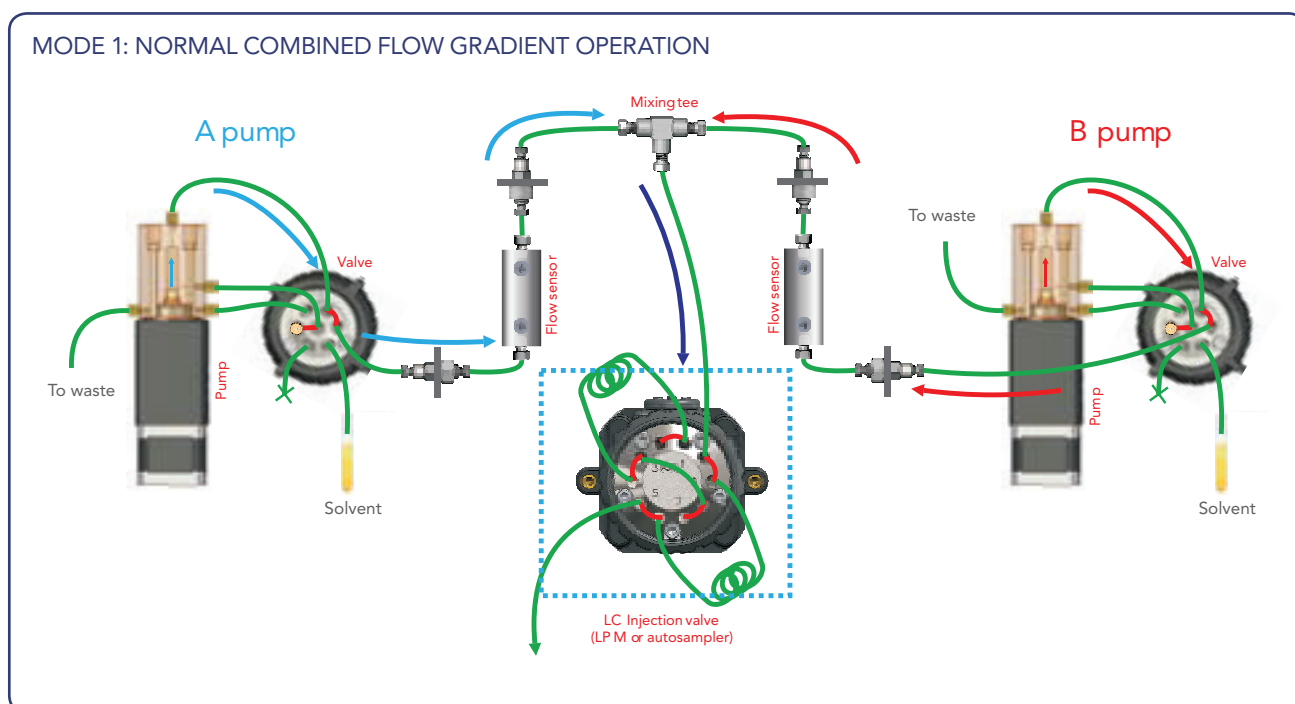
This hardware could be used for many sample preparation steps required in bioanalysis and lab-on-a-chip work.

For optimal operation, we recommend that you properly ground the transfer line between the valve and the MS source. Minimum internal volume and short lengths are desirable in the transfer line, to prevent bandbroadening, lengthy delay times, or adsorption of sample. For the analysis of phosphopeptides or other metal-sensitive analytes, we can offer non-metallic or specialized flow paths for this system.

All operational modes are supported internally via IDEX Health & Science controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided

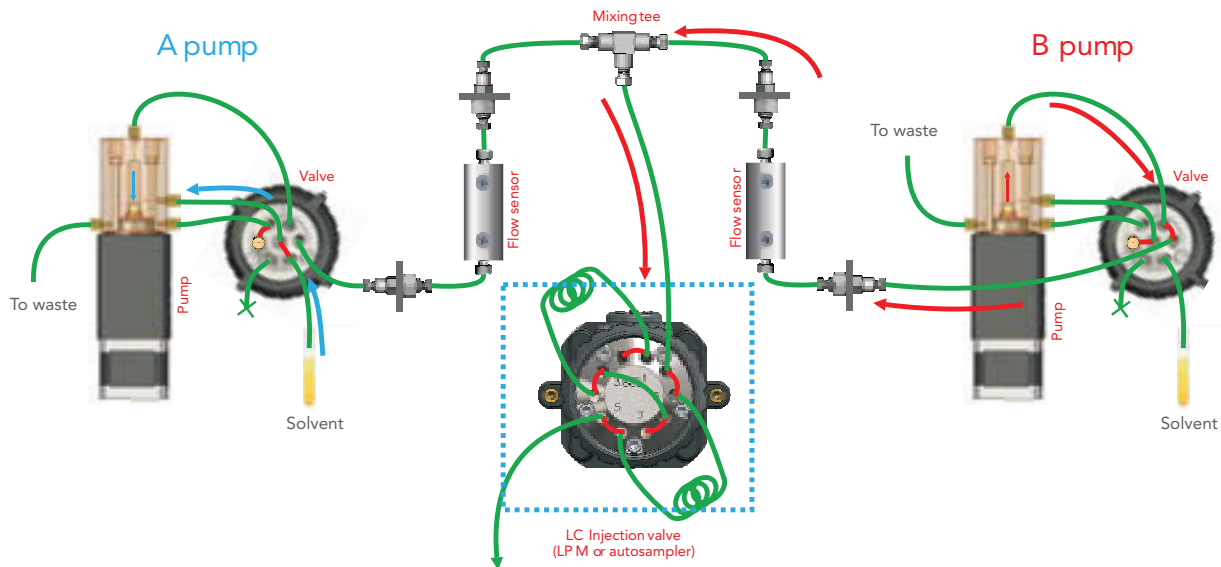
for evaluation purposes. This subsystem can be configured to run from any of the control schemes described in the System Control section earlier.

Complete tubing/fitting kits are created within IDEX Health & Science to support this design.

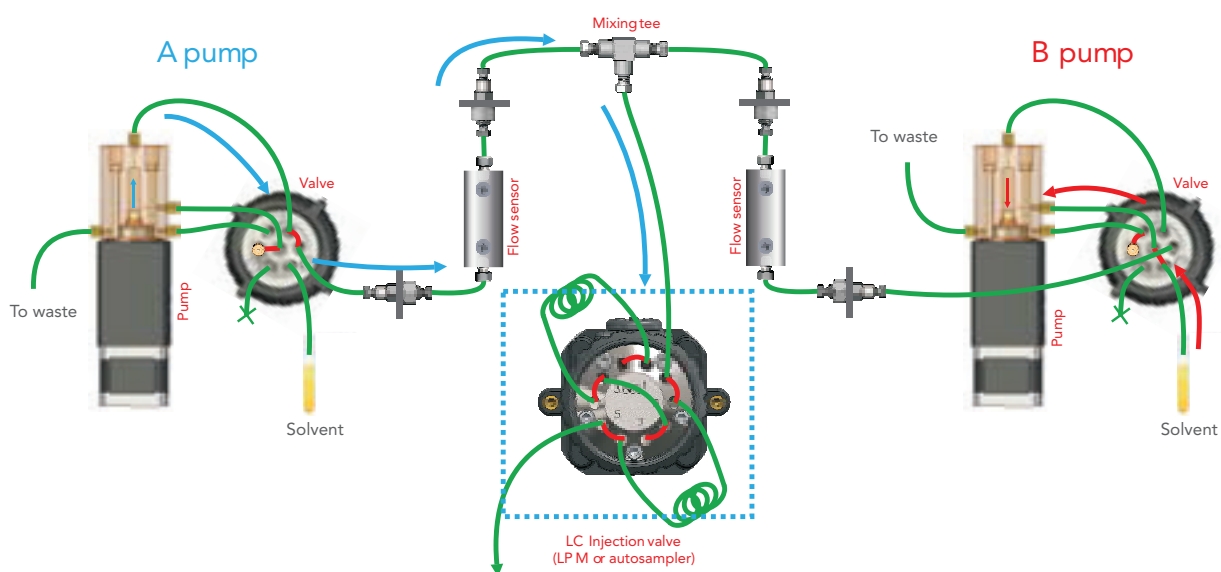


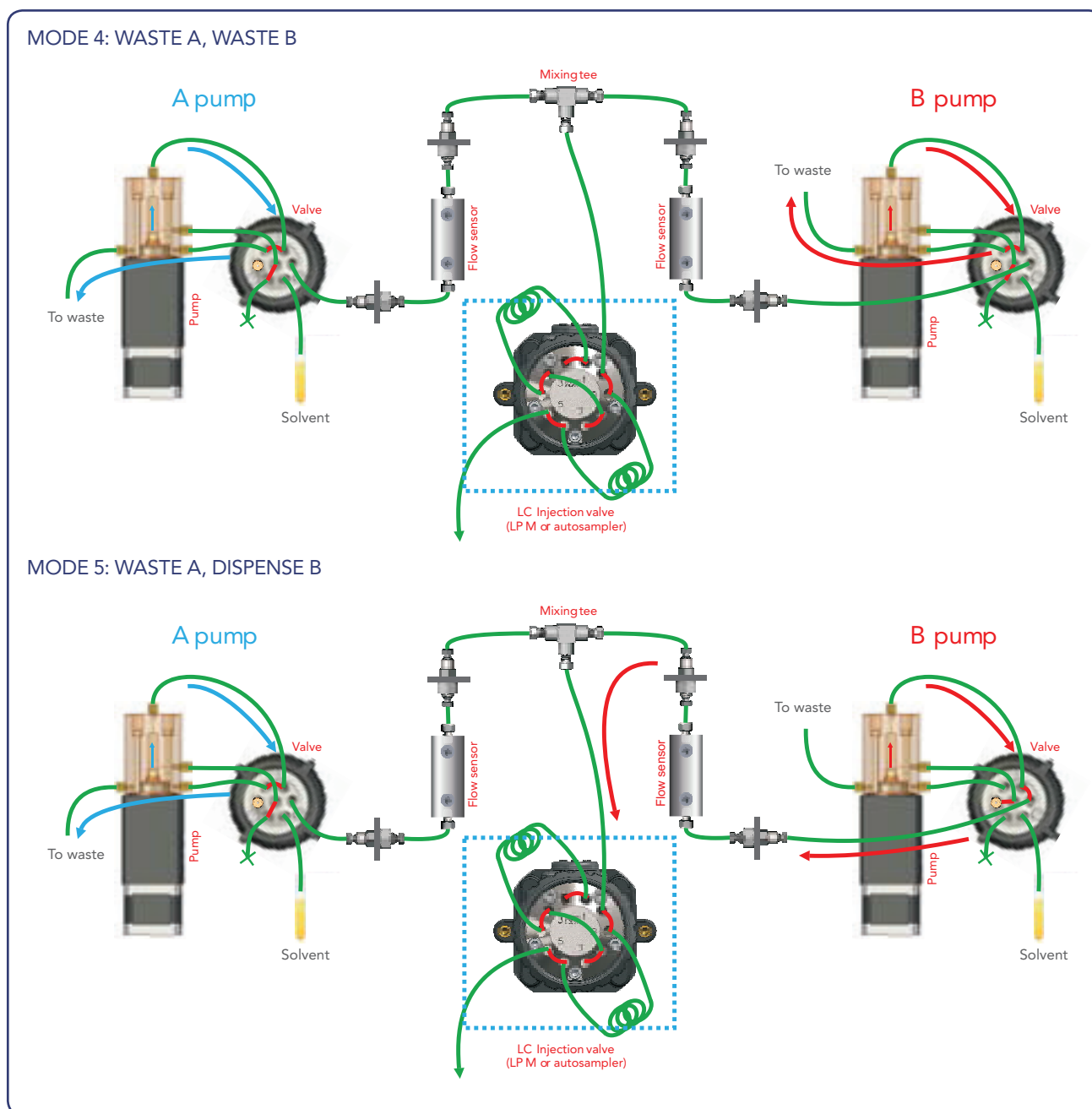
COMPONENTS BASICS — DESIGNING WITH VALVES & PUMPS

MODE 2: FILL A, DISPENSE B

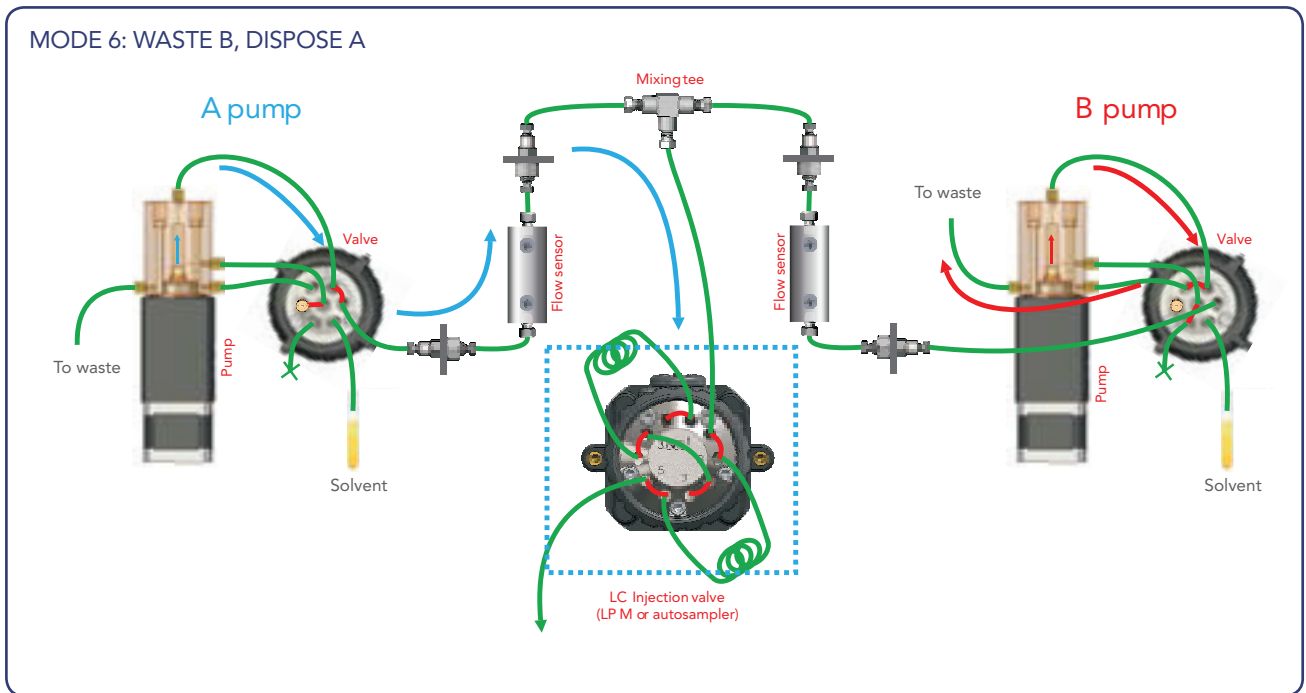


MODE 3: FILL B, DISPENSE A





COMPONENTS BASICS — DESIGNING WITH VALVES & PUMPS



SOME USEFUL CONFIGURATION IDEAS FOR MASS SPECTROMETRY

Idea 9 — Sample pressurization, reaction, and dispensing

This idea is for the trapping of a sample in a loop or on a column, followed by pressurization of the sample, then ejection of the sample after reaction. Column-based chemistries, such as catalysis or bio-reactor processes can be performed on the sample, and the processed material can be ejected from the system after a pre-determined incubation time.

Sample processing is facilitated by “injecting” the sample from the loop into a plugged or partially plugged port on a second valve. A pressure sensor monitors the drive pressure. Our controller circuitry is programmed to drive the pump to pressurize the sample to a set point and then wait for a period of time before ejecting the sample.

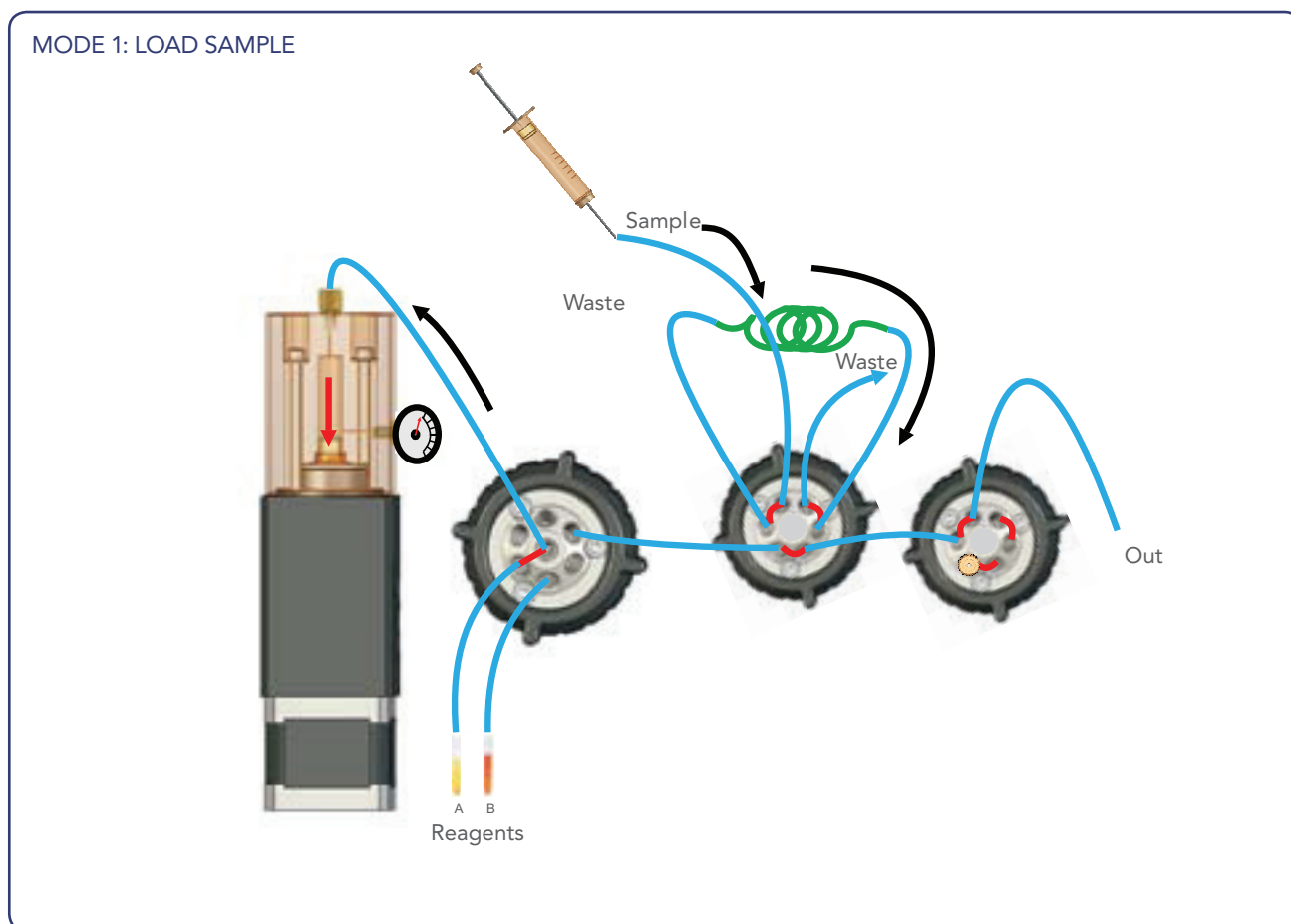
The drive pump can be loaded with a variety of reagents that can be subsequently applied across the sample if it is adsorbed onto a column or other such material in the sample loop. Similar applications of this hardware therefore include desalting, solid-phase extraction, or other processing steps. This hardware could be used for many sample preparation steps required in bioanalysis and lab-on-a-chip work.

For optimal operation, we recommend that you properly ground the transfer line between the last valve and a MS source, if present.

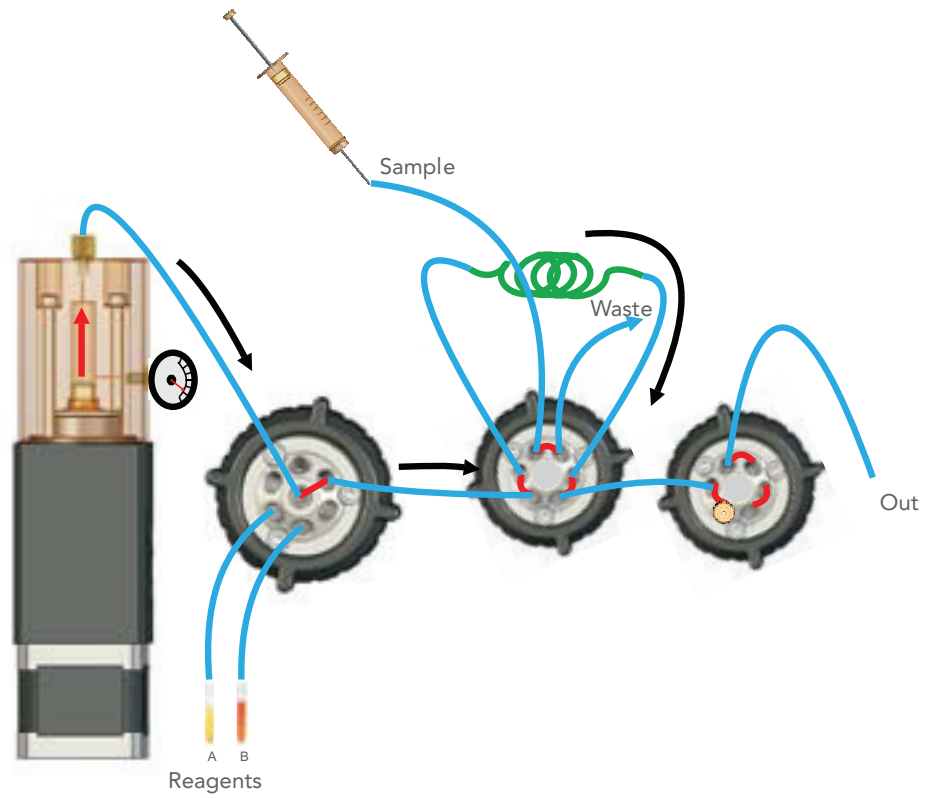
All operational modes are supported internally via IDEX Health & Science controller cards, so OEM integration is simplified, and a scriptable Graphical User Interface (GUI) can be provided for evaluation purposes. This subsystem can be configured to run

from any of the control schemes described in the System Control section earlier.

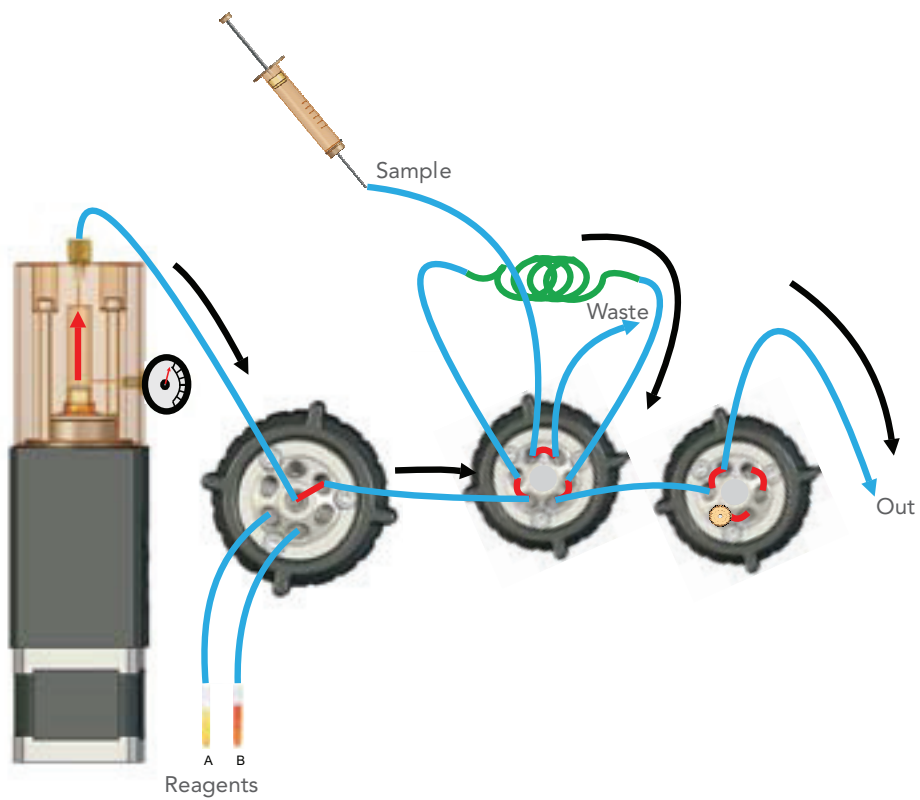
Complete tubing/fitting kits are created within IDEX Health & Science to support this design.

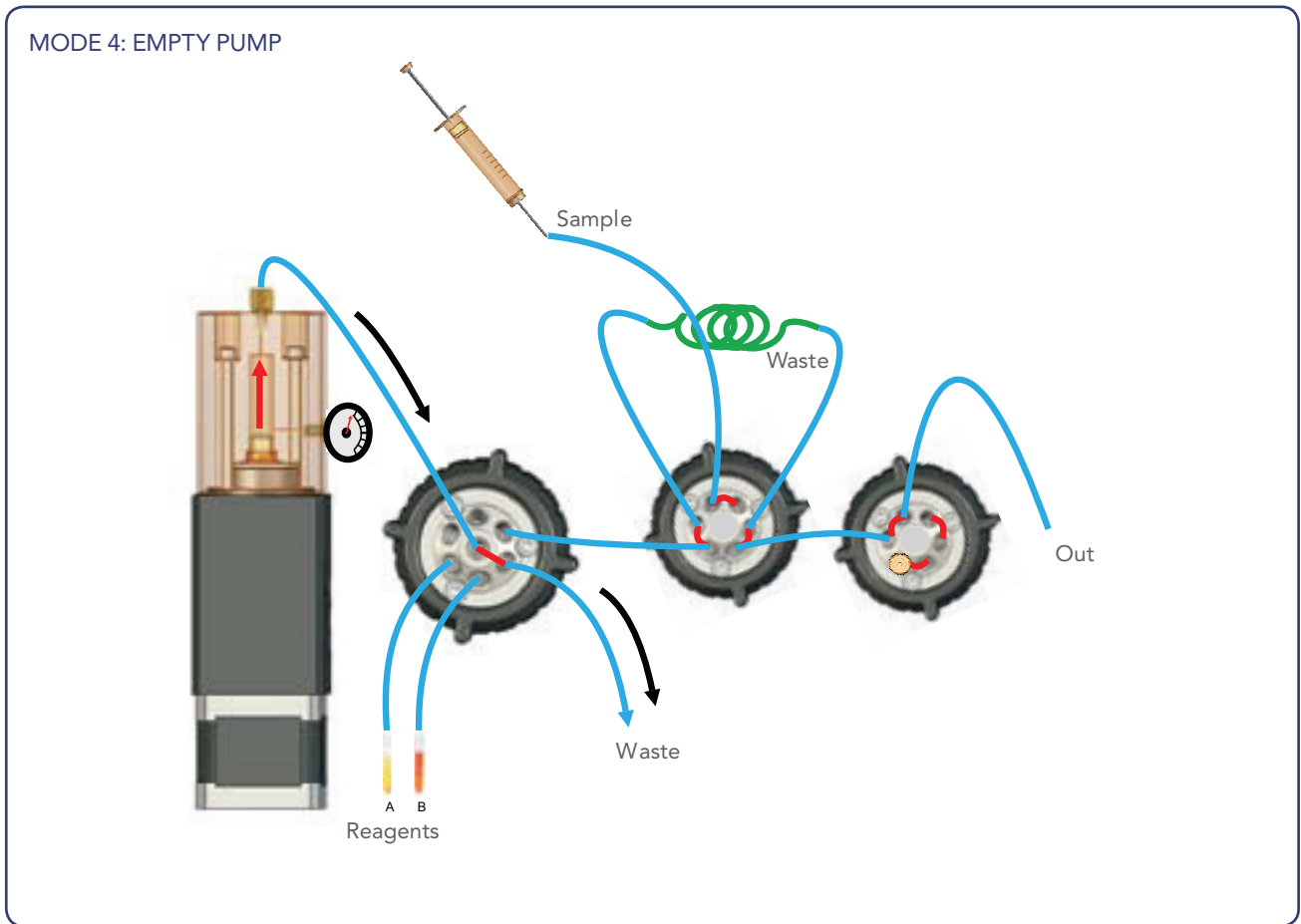


MODE 2: PRESSURIZE SAMPLE



MODE 3: EJECT SAMPLE



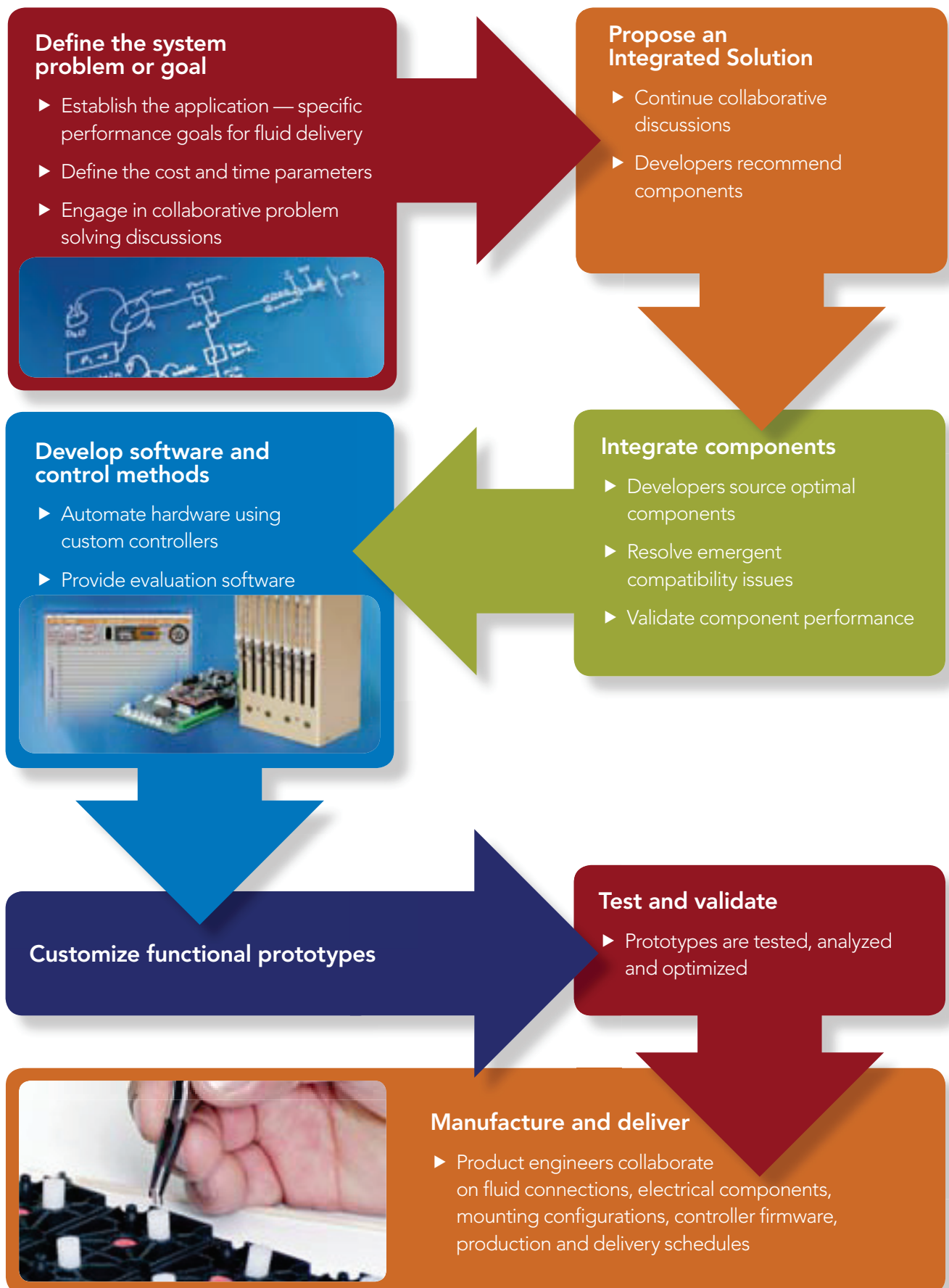


Working with IDEX Health & Science



Whether you have a component question or are interested in a customized fluidic solution, we are dedicated to providing valuable insight from our in-house fluidics experts about everything from the design and development process to manufacturing and troubleshooting of fluidics equipment. IDEX Health & Science specializes in innovative and optimized fluidic systems.





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