Overview

The overall purpose of a microfluidic device is to both house and control the flow of liquid droplets in spaces with dimensions no larger than a few millimeters in length. Due to the miniscule nature of these droplets, traditional liquid control techniques have been abandoned and new methods and devices have been created to facilitate complex fluid handling operations of droplets at the scale of microliters. These new, multi-layered devices now commonly employ control systems analogous to electrical circuits in execution and are currently dependent upon external instruments to control the movement of the fluids as well as to provide any additional functions specific to the desired end product of the device.[1] The purpose of this technical paper is to review the underlying technology of pressure generators and solenoid controls and their applications with regards to microfluidic devices.

Off Chip Components: Pressure Generators and Solenoid Controls

Microfluidic chips currently have need for external electromechanical components for the control and actuation of sample flow in the fluid layer. Most notably, the primary external components are the generators which provide pneumatic pressures or vacuums to the control layer of the chip, as well as the solenoids which regulate the output of those pressure generators.

Pressure generators are most commonly positive displacement pumps (PDP's), trapping some amount of fluid or gas in a fixed volume and forcing it into chambers of increasing or decreasing size. By altering the volumes of the different sections within the pump, PDP's create either pressure or a vacuum at the output. Although many different types of pumps exist which could create pressure, such as, a simple rotary pump would fit the requirements of a microfluidic chip perfectly due to the rotary pump's capabilities of operating in low pressure liquid and gas applications such as air injectors in vehicles or in chemical vapor disposition systems. These pumps, using either internal gears or a rotary vane, commonly have a variable pressure range that can be produced by either increasing or decreasing the speed at which the gears or rotary vane rotate within the mechanism.[2] Lower RPMs result in lower pressures being produced.

Market prices for rotary pumps vary from as low as $40 to as high as $9,000 depending on the desired substance, range of pressures, and control over input and output velocity of the fluid or gas.[3] An INGERSOLL-RAND Rotary Air Compressor for instance can create up to a maximum of 150 psi, or a little over 1000 kPa, stands 5 feet tall, requires 37.6 amps at full load, and currently costs $9,087.[4] On the other hand, Mr. Gasket Micro Electronic Fuel Pump only produces a range of 3.5 psi, about 2.4 kPa, is a few inches in length, width, and height, and only costs about $50.[5]

To complement the selected pressure generator, solenoid valves would function as a switch to determine whether the generated pressure is applied to the output or if it is held in check. The valve would operate by running a selected current through a solenoid; when the current is applied, the solenoid activates, raising the internal mechanism and opening the valve. Unlike the pressure generators, solenoid valves are priced quite a bit lower, ranging primarily from $5 up to $1,000 depending on the maximum pressure ratings, number of inputs and outputs, and the materials used. It should be noted that most plastic solenoid valves include gaskets in their internal mechanisms and so have minimum pressure requirements. Overall, a reasonable solenoid valve, such as a Brass Liquid Solenoid Valve, costs $24.95, has no minimum pressure requirement, and has dimensions of only a few inches at most.[6]

Applications of Pressure Generators and Solenoid Controls on a Microfluidic Device

To operate the microvalves of the microfluidic chip, the control layer is connected to the selected pressure generator.[7] This generator is separated from the microvalves in the control layer by solenoid valves, enabling a microcontroller to decide whether the microvalves should operate in the open or closed state. If the microcontroller opens the solenoid, the pressure is applied to the connected passageway in the control layer and any conjoining switch valves are forced into the closed state. Likewise, if the solenoid is closed, the pressure from the pressure generator is cut off from the passageway in the control layer and the conjoining switch valves are forced open by the already existing pressure in the liquid layer of the chip. It should be noted that the control pressures for the switch valves can all be controlled by a single solenoid if the valves are intended to be simultaneously open or closed, reducing the overall amount of solenoids required.

This setup can be repeated in the case of a vacuum, separating the control layer from the vacuum pump with solenoids and controlling the solenoids with a microcontroller. An application for the vacuum would most likely include acting as an intermediary step in the fluid control process in which any previously filled chambers would be emptied, allowing further sample fluid manipulations without the risk of contamination from previous processes.[8] Furthermore, the pressures and vacuums created by the pumps could be used to regulate the pressures in the liquid layer of the chip which push the sample fluid from the high pressure chambers to the low pressure chambers when the microvalves allow movement in the liquid layer passageways.

References

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