Characterization of Micropumps for Biomedical Applications

Yousef Haik[1*], Jason Hendrix[1], Mohammed, Kilani[1], Paul Galambos[1], Ching-Jen Chen[1]
[1]Center for Nanomagnetics and Biotechnology, Tallahassee, FL 32310
*United Arab Emirates University, Department of Mechanical Engineering, Al Ain, UAE

ABSTRACT

A novel class of micro pump was developed at the Biomagnetic Engineering Lab at Florida State University. The pump operates by utilizing the viscous effects that are dominant the micro scale and by spinning a disk that contains a spiral and is in close proximity to a bottom plate. The pumps are highly compatible with biological applications as the system does not use thermal actuation which could denature proteins. Initial steps to characterize the pump consisted mainly of the 2D solution of the flow field. This paper outlines the secondary steps of characterization of this pump which includes internal resistance testing and CFD analysis.

Keywords: Micropumps, Surface micromachining

INTRODUCTION

MicroPumps were developed which utilize viscous drag. The pumps were fabricated using Sandia National Labs SUMMiT process which is a five layer polysilicon deposition process. One of the major benefits of this process is the all in one manufacturing. The entire pump and all actuation devices are fabricated at one time as a complete system. There is no assembly required. This technique allows for a high level of integratable systems to be used in a 'Lab-on-a-Chip' system. The major operating principle is the spinning of a top plate that contains a protruding spiral that is in close proximity to the bottom surface.

The internal resistance of the pump was an area of interest to determine and a developed priming procedure was utilized to determine this piece of data. The only

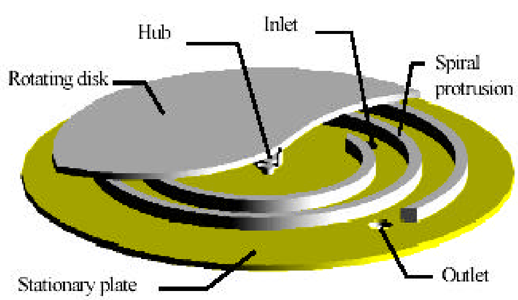

Figure 1. Three dimensional representation of spiral pump

modification to the procedure was introducing a hydrostatic head pressure. This was accomplished by raising the reservoir to a height higher than the outlet of the pump. The pressure was determined by computing the pressure with the following equation:

$$P = \rho g h$$

In order to keep the pressure constant, a vessel of sufficient area was used as to not alter the height of the fluid inside the reservoir over time. The setup of the experiment appeared as in Figure 2. The height of the reservoir and therefore the pressure of each trial were altered and varying volumetric flow rates were measured. The flow rates vs. pressure data were then graphed and displayed in Figure 3. The graph was expected to be linear from the equation:

$$P = IR$$

where P is the driving gauge pressure, I is the mass flow rate, and R is the internal resistance.

The first step of characterization was a theoretical solution of the flow space performed by Mohammed Kilani et al. To further verify some of the assumptions made in that analysis and to further characterize the pump, a CFD model

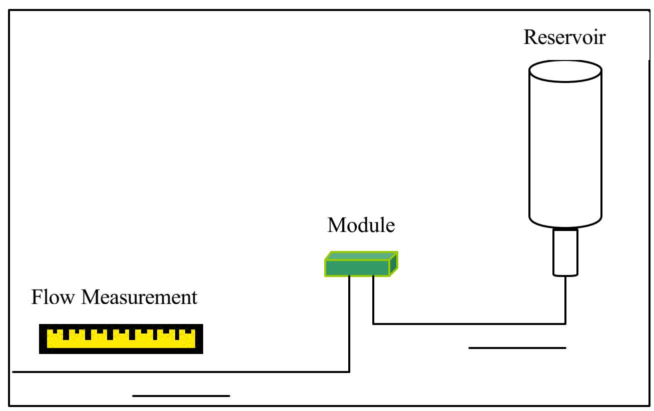

Figure 2: Internal Resistance Set-Up

of the device was developed. The geometry of the device was imported into the CFDRC program and meshed into three dimensions. Precise geometry measurements were determined by using a Fixed Ion Beam cut and scanning the device. To confirm and further validate the internal resistance tests, a CFD model of the pump was constructed[6]. After setting the boundary conditions to match the experimental trials, the mass flow rates were computed. The computations tend to support the experimental data. At low pressures, the resistance values are very similar, 9% different, and the graphs nearly overlap. However, as the pressure increases, the CFD model begins to give lower flow rates than were measured in the lab. This result tends to agree with a current hypothesis of an increased flow rate due to deflection in the channel geometry. One of the assumptions of the previous theoretical solution was to neglect centripetal effects. This assumption was verified as valid during the CFD analysis by plotting stream lines in the flow field a witnessing their position being fixed around the spiral.

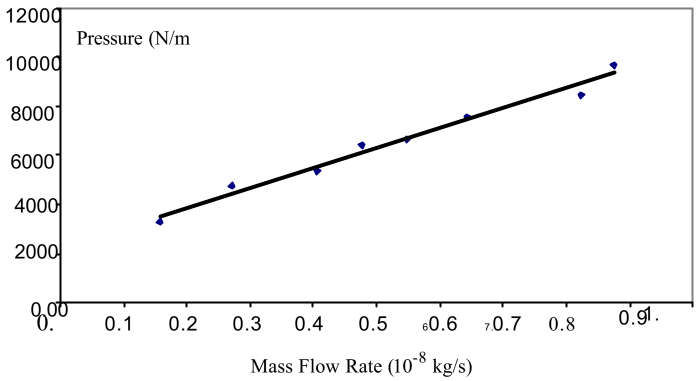

Figure 3: Head Pressure vs Flow Rate : No Pump Actuation

During the process of testing the devices some components of the pump tended to frequently fail. The first such failure was a combined effect of the torque of the TRA and the gear transmissions of the pump. Two style transmissions were used in the original design. One had a gear ratio of 0.36:1 and the other transmission had a ratio of 4.3:1. Both transmissions coupled with the capability of the TRA proved insufficient to turn the pump gear. To complicate matters further, the TRA very often ran sporadically and occasionally broke at the ratchet pawl head. Further frequent failures were found at the gears themselves. It was common to have a gear break away from the substrate at the hub. The most common gear to break free was the very small gear that is pointed out in Figure 4. This failure was due to the torque requirements of the pump.

The most common and by far the largest error with the

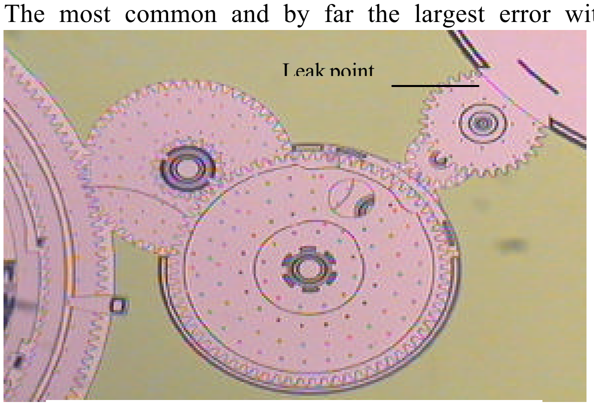

Figure 4: Gear Failure and Leak Point

pumps appears to have occurred during manufacturing. The poly-4 dimple used in the cover of the pump very often appears to have fused to the poly-3 top spinning plate of the pump. This idea was proven through the use of an FIB procedure which cut through the top surface and showed the dimple fused to the plate. This leaves the TRA and gear transmission trying to spin what is supposed to be a free-to-rotate plate in poly-3 that is fixed in place to poly-4 do to the error. So instead of having five pumps per module, it was fortunate to find one pump per module that was free to rotate.

With torque requirements causing such large problems, other fluids than water were attempted as the pumping fluid. As the pumps operate on a viscous drag principle, using a fluid with lower viscosity should reduce the torque required to turn the pump at the cost of higher performance. Fluids that were investigated and used were silicon oil, methanol, 95:5 methanol: ethylene glycol, and 50:50 methanol: ethylene glycol. Silicon oil proved to have such low surface tension that it was able to leak out of the etch release hole. This rendered the fluid unusable. 100% methanol, which has a surface tension of about ¼ that of water, also proved to be unsuitable for pumping. It would leak out of the interface of the gear transmission and the top plate/housing of the pump which is pointed out in Figure 4. The final fluids investigated were mixtures of methanol and ethylene glycol. Both fluids proved sufficient for priming the device, but were unable to be pumped. An analysis on the viscosity of both of these mixtures showed that they were in fact at a higher viscosity than water. This could very well be the reason the pump was unable to move these liquids.

With so many errors in the design and fabrication, actual pump characterization curves could not be developed at this time.

2 DESIGN MODIFICATIONS

In order to overcome the before mentioned pump failing points, design modifications were submitted for production. The first failure point corrected was the problem of torque. Both the TRA and the gear transmissions were modified. The TRA used in the previous device was the first and oldest of the TRA's designed. A more recent TRA has been designed[4] which has higher torque outputs than the original and operates less sporadically. This higher output and more reliable TRA coupled with the new transmissions of 1000:1 and 2000:1 gear ratios should eliminate the error of low torque due to the driving mechanism. To further alleviate the problem of torque, each pump was reduced in size by 25% thus reducing the torque needed to turn the pump gear.

Modifications were also made with the TRA ratchet pawl. This very often broke in previous trials. The connection point and size of the head were increased in width to add more lateral support. Along the same idea, the small gear in the transmission would also commonly break and each hub in the new transmission was made larger to give a greater surface area contacting the substrate.

References:

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