A Study on Micro Flow Sensor Using Diamagnetic Levitation

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***Abstract*— This contribution presents a concept for the measurement of flow with laser sensor and magnetic levitation in microfluidic systems. Modelling of the flow and physical property diagnosis is crucial in microfluidic system design. The system is based on the displacement measurement of a levitated magnet in a channel with a laser sensor. On a pyroliytic graphite in the channel, levitation of the magnet in the channel is fixed by a ring magnet (NdFeB). The ring magnet is controlled by a micro stage that allows movement in z axis. Displacement in x axis is observed when variant flow rates are applied to the levitated magnet. Displacements are determined via laser sensor. Pressure and displacement values under flow and magnetic field are determined with multiphysics via FEM program (COMSOL). Displacement of the magnet is detected by the designed flow sensor; and the flow rate is detected by numerical analysis method using the data taken from the laser sensor with a C# program.**

Keywords— microflow, microflow sensor, sensor, magnetic levitation, diamagnetic levitation, pyroliytic graphite.

I. Introduction

Micro robots which are levitated by magnetic forces are very useful methods for many chemical and biomedical applications such as cell manipulation in micro channels.[1]. Lab-on-a-chip technologies, which increased significantly in recent years, are based on manipulating the flow in a micro channel and movement of particles in the flow principle. That is why effective controlling of microfluidic systems are very important. Modelling of physical and mechanical properties of the behaviour in micro channel is very important issue for efficiently designing microfluid platforms. Measurements of physical properties like flow rate in micro channel, viscosity and density are relatively hard. Micro systems with limited geometry invalidates conventional methods. [2] Hilber and his team measured fluid density and viscosity in microfluidic systems by diamagnetic levitation, using hall effect sensor. The research investigates the relationship between viscosity and density of a fluid and the damping of the resonance curve, and suggests a scaling device utilizing this relations. [3] Lammermk and his team developed a microfluid flow sensor based on thermic anemometer principles.[4] Abadie and his team observed that a passive levitated sismic mass does standart spring oscillation in passive low frequency nano force sensor design utilizing diamagnetic levitation. Because rigidity is moderately close to linear; it is obvious that force can be measured by changing the input value. [5] The spring-mass model that Abadie and his team observed has been seen in our system also. Literature studies have shown that most of the research is viscosity and density oriented. In contrast, flow rate in the channel is detected using laser tracking with diamagnetic levitation and measured without mechanical contact in our study. Movement of the magnet in micro channel is caused by the interaction of the magnet with the flow and magnetic field. In the suggested system, the flow is laminar and between 100µl/min - 8000 µl/min

II. System Methodology

Pyrolytic graphite in an acrylic container and the channel is shown in Figure 1. Magnet is in the channel. NdFeB (neodymium) ring magnet functions as lifter magnet in the system connected to micro stage. Micro flows between the flow rates 100µl/min and 8000 µl/min are applied to diamagnetically levitated magnet in the channel via syringe pump. Deionized water is used as fluid. x-z axis displacement of the magnet is measured with Micro-Scanner brand laser sensor. Levitation height is found between 1.25-1.4 mm in conclusion of experiments and analysis. Olympus SZX-7 microscope and Point Grey GS3-U3 camera is used for levitation confirmation.

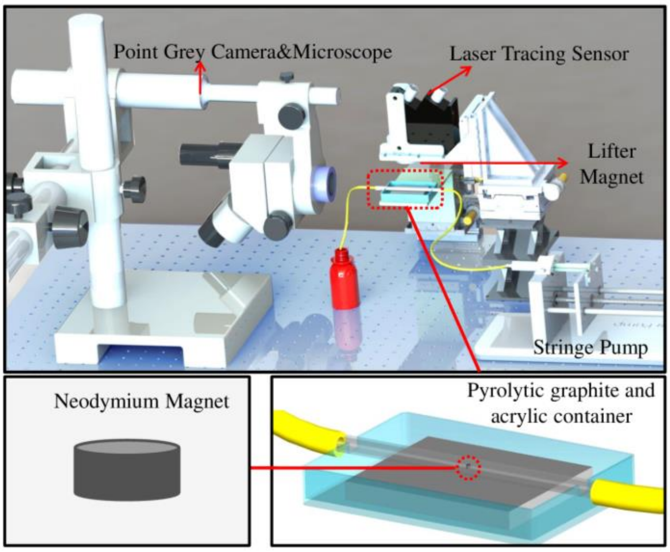

Figure 1. Figure shows the experimental setup. Flow rate in micro channel is detected with diamagnetic levitation utilizing laser tracking.

III. MATHEMATICAL MODEL

This chapter covers the issue of mathematical parameters. Forces applied to the magnet in channel on z axis is shown. Glass channel is put on pyrolytic graphite which is in an acrylic container. Displacement of diamagnetically levitated (via lifter magnet) magnet when 100-8000 *µl/min* flow rate is applied is detected with laser sensor.

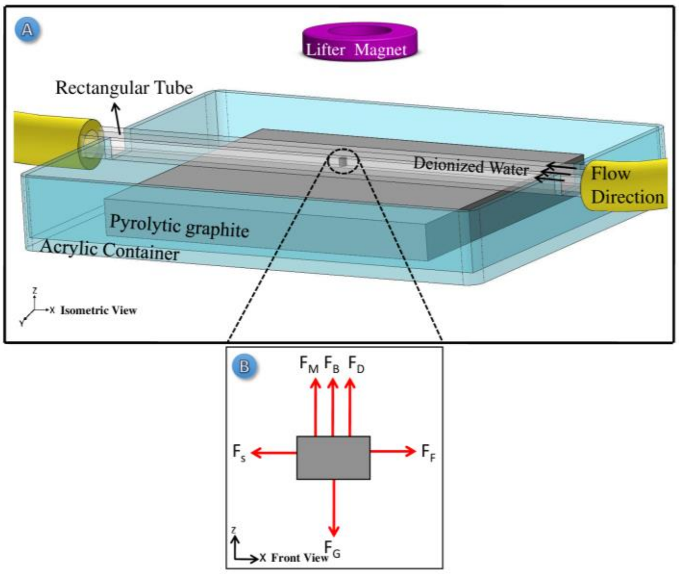

Figure 2 Figure shows the z axis levitation of the magnet in the channel and forced applied to it. Figure 2-b shows free body diagram of the object**.**

When flow dynamics are generated, flow rate is between 0.2 mm/s-16.66 mm/s. Reynolds number is quite low in this rate; which allows us to express the system flow with Navier-Stokes equations freely. Flow limits are expressable with Navier equations. Because M<0.3, The fluid is incompressible. So the fluid is constant and not dependant on time. When the forces applied on pyrolytic graphite is calculated, it has been benefitted from Demircali and his team's method of finding optimum parameters under micro robot control. [6] According to given calculations, a pyrolytic graphite which has the measurements of 40x50x4.83 applies a force of 75µN. Because our system has the pyrolytic graphite with same measurements, diamagnetic force is accepted as 75µN. The total force acting on the magnet is calculated as 3.23µN when the forces acting on the magnet given in Figure 2 are calculated.

IV. SIMULATION RESULTS

This chapter analyzes the flow applied on diamagnetically levitated magnet and the effects of magnetic field. Simulations are created using COMSOL Multiphysics. Flow module is used for modelling flow area and boundary conditions, AC/DC module is used for the effect of magnetic field on the object. Flow rates between /min-8000 µL/min are applied on diamagnetically levitated magnet in the channel.

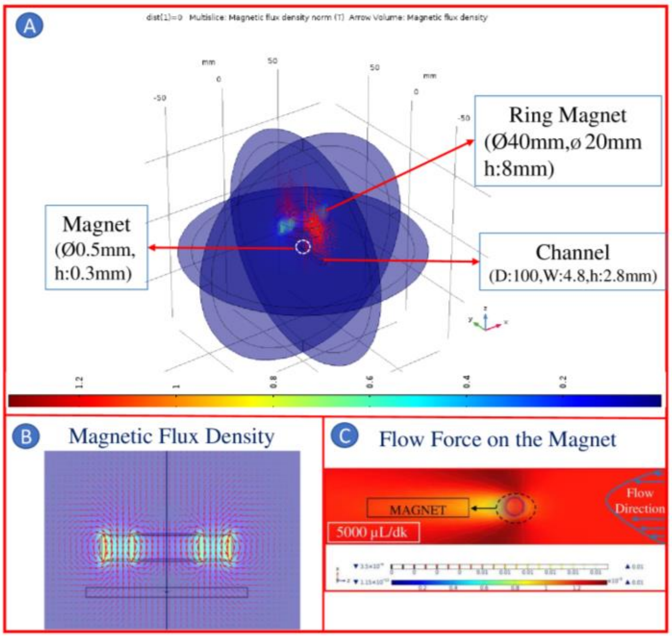

Figure 3 A) System dimensions used in the Comsol analysis are shown. Lifter magnet and permanent magnet are aligned to the center of the lifter magnet while pyrolytic graphite is placed on the bottom surface.**B)** shows that magnetic flux density between Ring Magnet and magnet in the channel **C)** Shows that flow force effected on the magnet when flow rates 5000 µL/min.

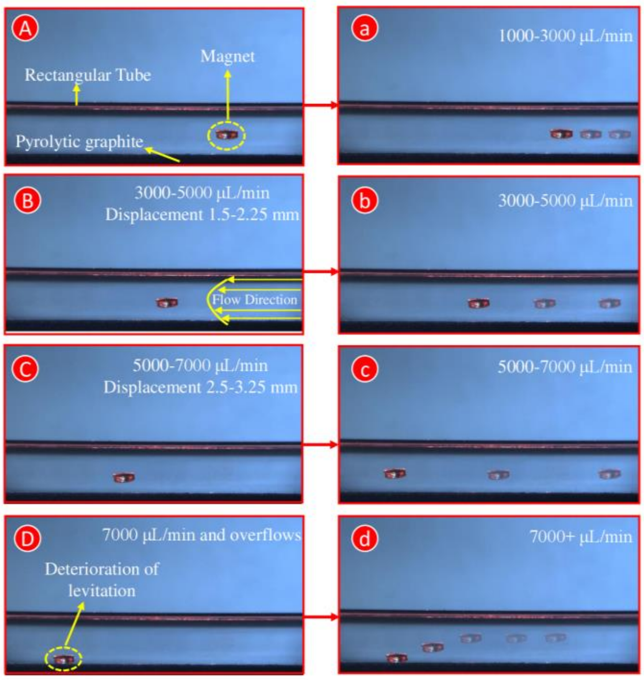

Figure 4 Images captured from Point Grey microscope camera during the experiment. Figures A-B-C-D show the amount of displacement depending on the flow rate. a-b-c-d shows the applied flux-dependent behavior of the magnet.

V. Experimental Work

This chapter analyzes experiments and experimental setup. Within the experiment, flow rates between 100-8000 µL/min are given to a channel containing diamagnetically levitated cylindirical magnet. Displacement of accelerated magnet is measured utilizing laser sensor. Due to experimental results, magnet moves between 0.00155 and 3.288 mm. 0.00155-1.5 displacement was measured at a flow rate range of 1000-3000 µL / min. The displacement amount in the range of 3000-5000 µL / min flow rate is measured as 1.5-2.25 mm.

At flow rates above 7000µL / min, the levitation of the magnet deteriorated. This means that the recommended sensor system can receive data up to a maximum of 7000µL / min. When the flow and magnetic forces are compared with the generated mathematical model, Figure 5 is obtained.

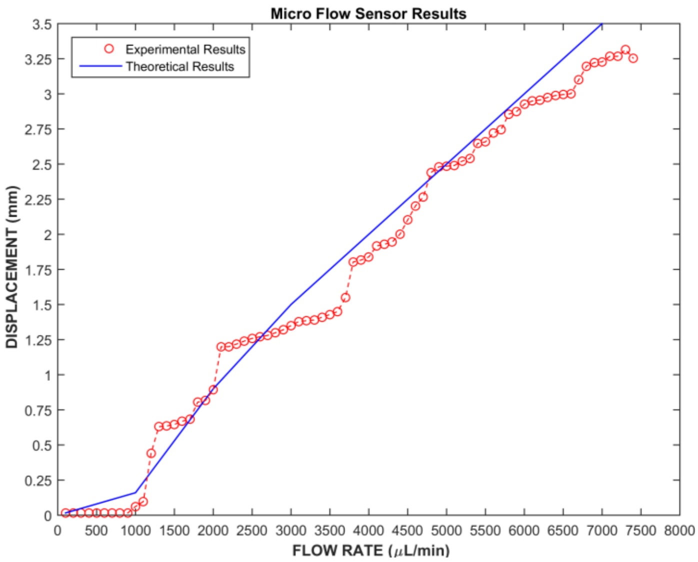

Figure 5, Comparison of experimental and mathematical results

Experimental results and the data from the mathematical model is compared in Figure 5. When the mathematical results and the experimental setup results are compared, the relative error rate is found to be 1.84%.

VI. Conclusion

In conclusion, magnet's levitation collapses when approximately 7000µL/min flow rate is given, thus measurements can't be made. In contrasts sensor measured a constant value (0.0155mm) between 100-1000µL/min, because sensor's measurement sensitivity is below measuring range. This marks the levitation limits of a cylindrical magnet with 1 mm diameter and 0.3 mm height, in a rectangular channel with the measurements 2x4 mm. Experimental results are compatible with mathematical and simulation results. As seen in experiments, over a certain flow rate magnet oscillates; this shows the similarity of our system and spring-mass-damper system.

VII. References

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