MOTION OF PARTICLES IN IN A PARTICLE SHAPE DETECTOR

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Abstract- **In this paper the motion of particles (biological cells) in a particle shape detector was investigated with Finite Element Modeling. It was found that torque acts on particles, whose rotation is fixed, whenever they travel off the center in microchannels. The magnitude of this torque depends on the flow velocity, the particle position and particle geometry. In the real situation, when the particles can move freely in the liquid, the torque causes rotation. This rotation of the particles introduces measurement error in the proposed particle shape sensor. Though positioning the particles to the middle of the channel is possible by three dimensional sheath flow it causes lower optical resolution. This tradeoff is also investigated.**

Keywords- **BioChips, *Finite element analysis, Microfluidics***

I. INTRODUCTION

BioChips or Lab-on-Chips is a rapidly evolving field of micro electro mechanical systems (MEMS). The main objective of this area is to shrink down a laboratory or part of it into a micro scaled device. Advantages which are gained include small sample quantity, faster analysis, portable devices etc. In current state devices this goal has only been partially fulfilled. The measurement volume decreased dramatically but there are only few devices which have integrated sensors and actuators on chip. Difficulties arise not only from miniaturizing the sensor, but also from loosing some non integrable auxiliary systems (e.g. complex optical focusing system), too. In this paper first an integrated micro device will be shown [1] which is intended to measure the shape of microparticles. Unlike currently available macro-scale particle shape sensors, this device does not have an optical focusing system in front of the detector (photodiode array) and so particles have to travel close to the detector in order to obtain maximum resolution. In the second part of the article a finite element simulation is presented which shows that particles tend to rotate when they are in the off-center region of the microchannel. As the speed of the rotation is unknown it introduces error in the measurement. The decision is for the designer to find the optimum position for the particle to gain good optical resolution with little rotation introduced error. The last part of the article recalls the particle positioning method in microchannels by the use of sheath flow [2].

II. PARTICLE SHAPE SENSOR

The proposed particle shape sensor uses optical techniques to measure the two-dimensional image of the particles which pass through the device. The particles to be measured are suspended in a sample liquid which is pumped through a microchannel by a syringe pump. The microchannel has a one dimensional photodiode array situated on the bottom and is illuminated with an external light source. When a particle passes over the diode array it blocks the light. This “black” period is registered and the two dimensional shape of the particle is restored from it. Fig.1 shows the schematics of the sensor.

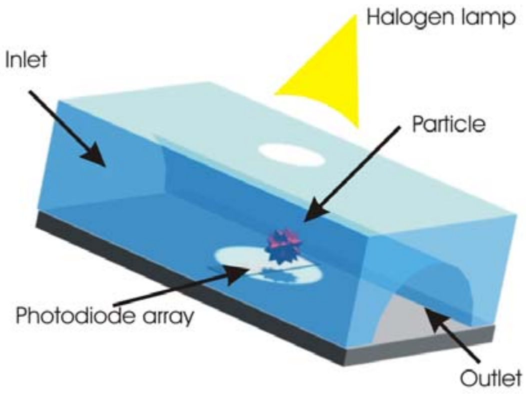

Fig.1: Schematics of the particle shape sensor

It has to be emphasized that the particles is scanned line by line in time, unlike in conventional cameras where the complete two dimensional shape of the object is registered at one moment of time. This means that any type of unknown time variation of the particle position introduces an error in the registered shape. In the next section it will be shown that such unknown behavior can be expected near the wall of channel. On the other hand as no optical focusing system is used the closer the particles would be to the array the sharper image could be obtained. This trade off has to be taken into consideration during designing the device.

III. PARTICLE MOTION IN THE PARTICLE SHAPE SENSOR

In the previous section it was mentioned that particles are preferred near the walls to receive maximum optical resolution. To investigate particle motion in this regime a finite element analysis was made using Ansys 8.1.

1.) Modeling

First a 200µm long 50µm high rectangle was drawn to model the microchannel in 2D. The microparticle was represented by an ellipsis in the flow.

2.) Boundary Conditions

To fully constrain the model the particle location had to be fixed and its velocity was taken to be zero. In this coordinate system (which is fixed to the particle) the walls have a relative motion. Zero pressure was assumed to be at the outlet and a parabolic velocity profile at the inlet. Fig. 2 demonstrates the vector plot of the velocity after executing the simulation.

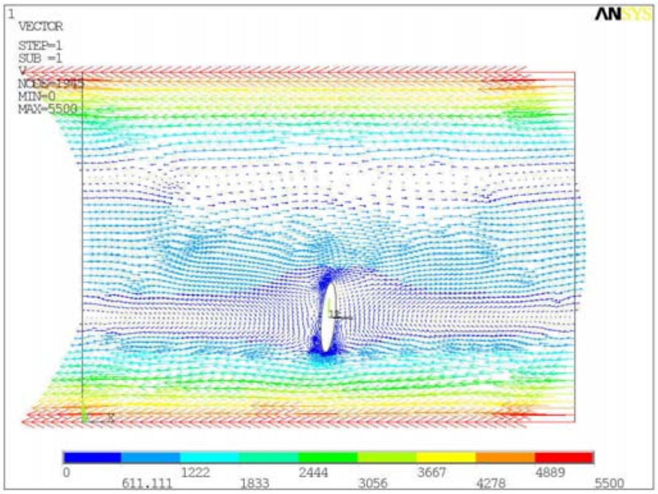

Fig. 2: Vector plot of the flow velocity around a microparticle in the microchannel

3.) Simulation results

After integration of the forces on the particle the simulation gave a net torque on the particle. This agrees with the situation in [2]. Based on the latter analytical calculation the torque causes particle rotation. This rotation is periodic but non uniform in simple shear Couette flow. To demonstrate that this is the case also in Poiseuille flow the particle was placed into the flow with different positions. Fig. 3 shows the torque versus the inclination angle of the particle. The figure can be understood in the following way:

1. It can be read from the graph that when the inclination angle is higher, that is the particle lays flat in the flow, the torque on the particle is smaller.
2. In free particle motion (when no force acts on the particle other then the one exerted by the fluid) no net torque can be present. However, the torque on fixed particles can be related to rotational speed of free particles.
3. Finally it can be concluded that particles have slower rotation when they are lying in the channel and higher velocity when they are standing. This motion is periodic as the sign of the torque never changes.

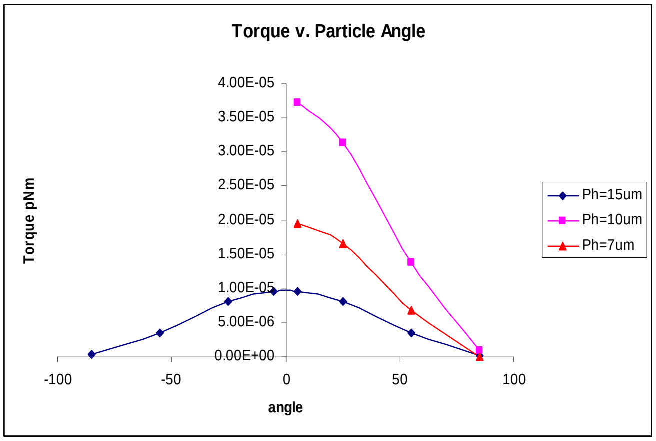

Fig. 3: Particle angle v. fluid exerted torque

Fig. 4 shows that the torque becomes higher as the particle position approaches the wall. This result is expectable as shear in the flow is higher at this region.

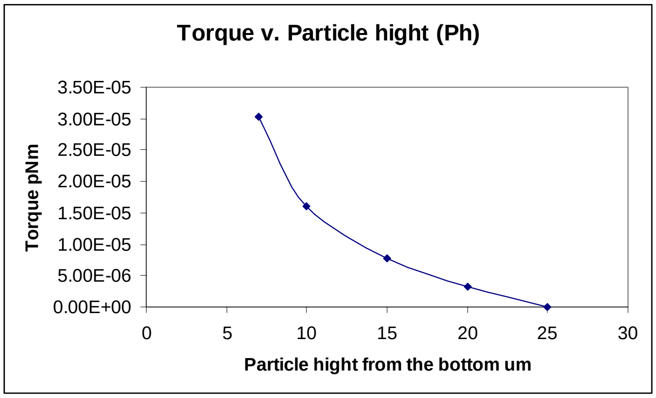

Fig. 4: Particle distance from the bottom of the channel v. fluid exerted torque

Note the strong dependency near the wall. As the device accuracy depends on the particle rotation, see above, it is clear that particle motion very close to the wall has to be avoided.

In addition to the high rotation of the particle near the walls the flow velocity also changes rapidly in this regime (see Fig. 5). This means that little change of position in the y axis results large change in the particle speed. Consequently it introduces a large measurement error as well (as the measurement relies also on knowing the value of the velocity).

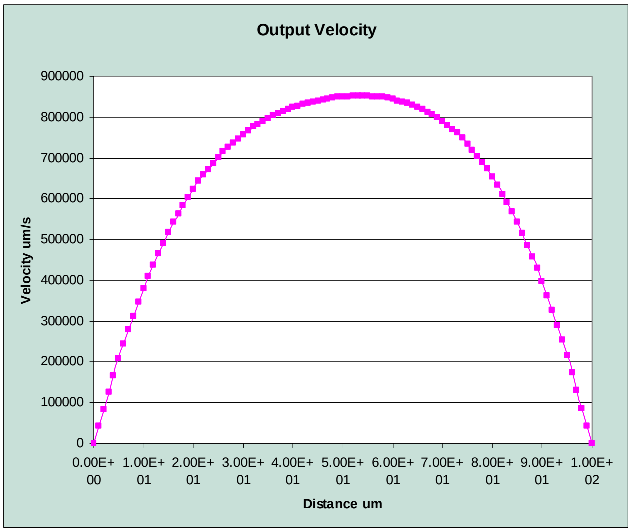

Fig.5: Flow velocity across the channel cross section

Fig.6 shows the linear relation between mean flow velocity and torque exerted by the fluid.

IV. PARTICLE POSITIONING WITH SHEATH FLOW

In the previous section it was shown that there is a strong relationship between particle position in the flow and particle rotation. In this section a method will be presented which can be used to position the particle in the flow. Using an appropriate flow control system the user of the device can find the optimum device parameters by adjusting the flow parameters.

Sheath was successfully used in microfluidic devices to concentrate the sample flow into a restricted region within the flow cross section [3]. Sheath flow means that the sample flow (containing the particles) is surrounded by a buffer flow. It can be established by using multiple fluidic inlets on the device. One inlet is for the sample liquid and two to four for the sheath liquids. The configuration of the inlets is demonstrated on Fig. 7.

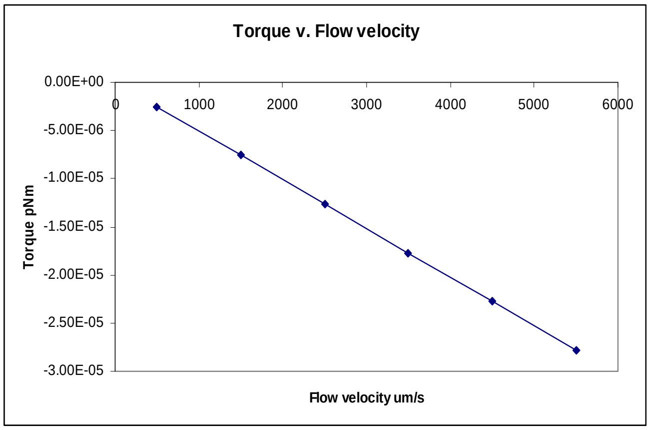

Fig.6: Flow velocity v. fluid exerted torque

The blue sample liquid coming from the middle bottom inlet is first constrained to the lower middle part of the channel by the sheath liquid coming from the bottom right inlet and than lifted to the middle regime by the sheath liquid coming from the bottom left inlet. The final area in the cross section occupied by the sample liquid can be seen at the outlet of the device. (The symmetrical behavior of flow used so only one half of the model was simulated in Fig. 7)

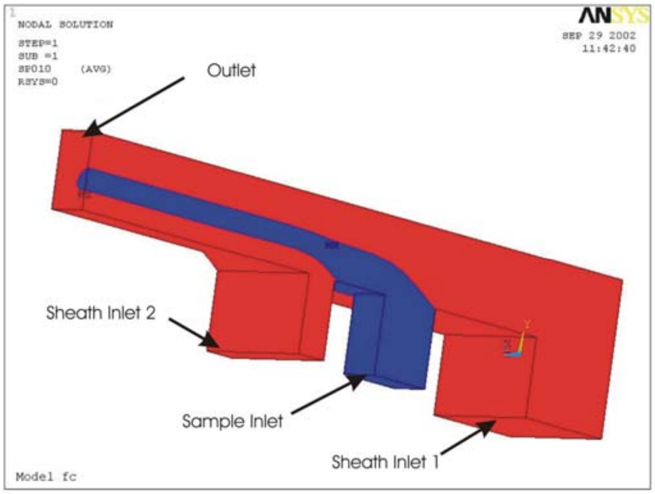

Fig. 7. Sheath flow in the particle shape sensor. The blue liquid contains the particles; the red liquid is the sheath liquid.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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