

Design Practice - 2
Prof. Shantanu Bhattacharya
Department of Mechanical Engineering
Indian Institute of Technology-Kanpur

Lecture - 23
Micropumps

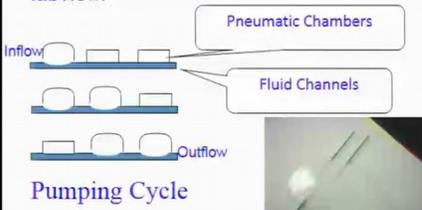
Hello and welcome to this design practice to module 23 I was talking about sensor and actuator design and we had designed various micro valves and you know micro pumps. We will left with some of the other displacement kind of pumps and how they how we designed them particularly at the microscopic length scale. And today I am going to talk a little more about peristalsis and then probably some other non mechanical principles for example thermo capillary or electro wetting effects.

So, where we do the same you know effects or we take the same effects as we did in the valving case and start doing you know some pump designs based on it.

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Peristaltic Micro-pumps for fluid transport

- Peristalsis is the motion of fluid in channels through a traveling contractile.
- This effect has been successfully utilized for the control of fluid motion.
- Pumping rates in the range of 10~12 microliters at pumping frequency of 10 Hz. has been attained.
- The pumps are 3 layered devices fabricated using Glass and PDMS and are energized by an offchip compressed nitrogen supply regulated thru labview.



Picture of the pumps

Ref:
(1) S. Bhattacharya, S. Gangopadhyay, K. Gangopadhyay, S.A. Grant, S.B. Kleiboeker, V. Korampally & Y. Gao, "Novel Onchip Platform for DNA Amplification", 05UMC076, 2006.

So, Let us first look into the very basic scheme that is deployed across a lot of applications for creating micro flow transport or microfluidic transport and this is a displacement kind of a system which is otherwise known as peristaltic micro pumps. Now I would like to just illustrate here that peristalsis happens even within human human beings and physiologically the intestines are supposed to perform the bile movement within our body through the the scheme of peristalsis.

So, it is about a traveling contractile so let us say if we had a flexible pipe and we are creating pressure on a certain area of that pipe so that the pipe contracts okay and then move that contract or contracted area forward or in the forward direction in a continuous manner then obviously the pipe being filled with fluid on both sides of this contractile would actually have fluid getting displaced in the direction of travel of the contractile where whereas as the you know as the the contractile moves forward.

The space that it creates at the back would have again a pressure difference because of which there would be flow into the region which is just at the rear end of the contractile. So, a direction of at the rear direction of the movement of contractile, so, this is a continuous peristaltic system and you can actually produce an effect in a slightly different manner by using a flow geometry through which you could discretize this contractile effect.

And this is shown in this particular illustration here let us say there is an inflow which is happening in a channel which is this is the channel which is colored in blue and it is being over seeded by a set of chambers which can expand and contract may be through pneumatic actuation. In this particular case we could have a again a controlled valve which bleeds in air into such chambers thus inflating.

So, the idea is to create a discreet contractile so as one of these chambers inflate you see the infinite condition being given here it will actually pinch because this channel down here is flexible so it will pinch on the channel to create a contractile effect. And then you can have one part of the channel contracted while the other is being contracted. So, that now the fluid does not move in this direction anymore.

And it starts moving only in the forward direction and in this manner if I could do two at a time you know and then at a certain frequency I should be able to transport fluid from the inlet side to the outlet side. so, this is exactly how you can operate a discretized fluidic system and obviously it demands a lot of actuation because all these are air actuated or pneumatically actuated where cylinders are being inflated deflated kalenna material which is flexible.

And creating a pinched effect on another set of flexible channels over which these cylinders are mounted. So, we want to somehow model this design this to estimate that because of such a

contractile and a travelling contractile what is going to be the outflow for every such contraction to happen within a flexible micro.

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Designing of a peristaltic micro-pump

A peristaltic pump has a three pump chambers and a circular unimorph piezodiscs as actuators. The pump membrane has a diameter of 4mm. The pump works with a frequency of 100 Hz. Determine the volume flow rate at zero back pressure if the maximum membrane deflection is 40 microns.

We assume that the membrane deflection follows the deflection function

$$d(r) = d_{max} \left[1 - \left(\frac{r}{R} \right)^2 \right]^2$$

$$\Delta V = \int_0^{2\pi} \int_0^R d(r) (r dr) d\theta$$

$$= \int_0^{2\pi} \int_0^R d_{max} \left[1 - \left(\frac{r}{R} \right)^2 \right]^2 r dr d\theta$$

$$= \frac{2\pi}{3} d_{max} R^2 = 3.35 \times 10^{-10}$$

And for this purpose I have a problem which has to be designed for there is a peristaltic pump having three pump chambers and there is a circular Luna morph which is let us say piezo disks and actuators in this particular case the bend and deflect into the chamber over which they are mounting. And so such a bending would create a volume outflow of the confinement of the chamber over which this uniform is being stationed.

Just as this being represented here for example this is that disk and this is placed over a chan chamber okay this is the chamber over which this disk is placed and because of the mechanical action as the piezo disc is actuated through a voltage signal that is bending okay. So, the piezo disc bends in this manner and over the outlets on both sides of this chamber it initiates the fluid volume which is present probably inside the chamber to exit the chamber.

So, we want to determine that because of the bending of the uniform of innum of disc mounted over such a chamber given some parameters for example the membrane dia of 4 millimeters for example and the membrane frequency of 100 Hertz we want to determine what would be the flow rate that it creates every time it bends and discharges. We can assume that there is no back pressure and you know the gauge pressure between what is inside the chamber and outside is zero both of them are donated prosthetic pressure conditions.

We further assume that there is a maximum membrane deflection of about 40 microns which the universe can bend up to and which would create this kind of a volume flow condition. So, we assume on the membrane so let me just start the computing here. So, we assume that the membrane deflection follows it is of course a circular membrane so this is from first principles particularly solid mechanics.

So, it follows the deflection function d at certain radius where d is this displacement. So, we were talking about the uniform displacement of the circular disk d okay. So, the d can be at various places from the center here to the sides and these are different d 's okay so this d function as a function of the radius here is related to the maximum deflection which is there in the center okay.

So, let us assume this deflection right here to be d_{\max} times of $1 - \frac{r^2}{R^2}$ capital R being the final radius of the Unimof and small r being the point at which the deflection d is being measured okay. So, a square of this so when we talk about estimating the the volume that is pushed out because of such a deflection. So, the volume ΔV can easily be given by a double integral both in r and Φ .

We assume that you know the distance r let us say this is how the disc is stationed or positioned in a XY plane and there is a certain distance r which has happened at a particular angle Φ . So, we can actually try to compute what is going to be the the volume of deflection at this particular radius and we assume a very small element at this radius from r to $r + dr$ okay. So, let me just write it again little better manner.

So let us say we are trying to talk about r and $r + dr$ okay as two elements this is the whole disk which varies between 0 and r probably so this right here is $r + dr$. And we want to find out that if supposing there has been a movement of this radius vector by an angle $\Delta \Phi$ this was Φ and so this movement right here which is describing an element okay which has been created by virtue of such a displacement.

So let us suppose we are looking across this particular disk position in the XY plane with the disk centered about the origin. And we are talking about a radius vector small r at which the deflection is to be measured we want to find out the deflection causes what kind of volume

change by virtue of the disk getting deflected okay. And the deflection happens out of plane into the Z direction for example in this in this particular case.

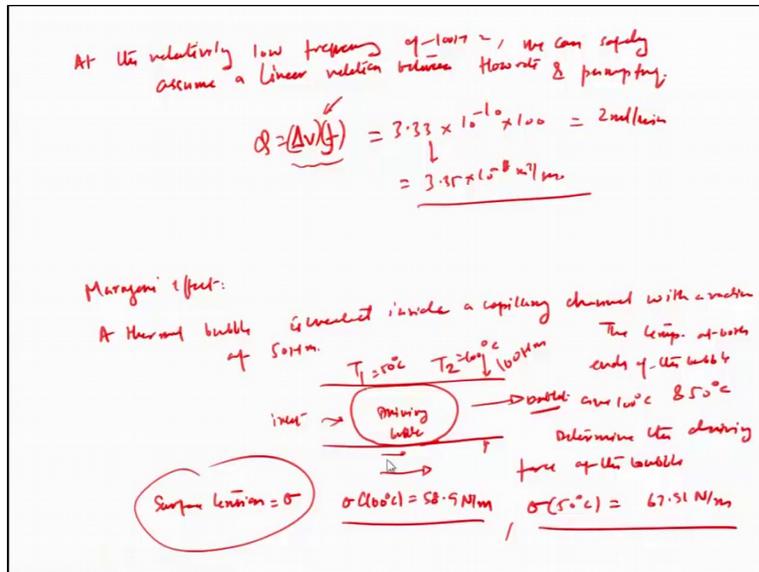
So, we take 2 neighborhoods points to formulate a small element let us say this point right here happens to be $r + dr$ and the radius vector which was actually at Φ goes to by an additional $d\Phi$ Φ angle because of which a small element is traced out like this and we want to find out the shaded element and how what kind of volume displacement it has caused. And so the best idea would be the ΔV in this particular element can be represented as the deflection at the particular point.

Let us say we assume this to be because of the deflection and because of the miniaturized nature of the dr and the $d\Phi$ we assume this element to have a total breadth of dr okay a total length which is given by $r d\Phi$ ok $r d\Phi$ is the length because obviously $d\Phi$ is the distance which has been moved and by a radius r . And then of course we have you know the distance which it has or the total amount of distance or the height that this element has moved is dr .

So, I am estimating that this particular element is a cuboidal element just because of the miniscule nature of the element and then we try to integrate it in the whole you know over Φ as well as over $d\Phi$ so you can see there are two variables so the Φ varies between 0 and 2π and obviously the dr would vary between 0 and r . So, if we solve this double integral by substituting $d\max 1 - \text{small } r / \text{capital } R \text{ square whole square } r d\Phi dr$, we are left with an expression 2π .

So, this is the closed loop solution $2\pi / 3 d\max \text{ square of } R$ and if I calculate this is the total volume because of the deflection which would happen to this particular piece or disc on giving a voltage signal this happens to be $3.33 \cdot 10^{-10}$ meter cube.

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Now such deflection is being carried out at a relatively low frequency so at the relatively low frequency of 100 Hertz we can safely assume a linear relation between flow rate and frequency so we can assume Q is ΔV times of F typically the frequency as the frequency increases that are going to be inertia dominated and so it may not be necessarily linear at that point so we just assume here because hundred Hertz is a very small frequency.

We can assume the initial delays to be neglected are very small so we have 3.33×10^{-10} to the power of -10 in 200 that is about 2 milliliters per minute of discharge rate or if we wanted to see what are the meter cube per second it will be 3.35×10^{-8} meter cube per second. So, that is how you compute how a peristaltic pump through a certain actuation we just made again in electrical manner would be able to give a certain delivery a flow delivery against you know atmospheric pressure.

So, that is how actuator design for peristaltic micro pumps can happen I would also like to give another non-conventional or non mechanical micro pump concept which is based on the Marangoni effect is the thermo capillary effect. Let us say we want to create a thermal bubble inside a capillary you already know how this effect was earlier illustrated for showing how to block the flows or valve the flows.

So, the capillary channel in this case has a radius of 50 microns and the temperature so let us say there is this channel here right here it has a 100 micron diameter 50 micron radius and you have created a bubble here through either thermal phase change or an electrolytic phase change and on

the temperature at both ends of the bubble are 100 degree Celsius and 50 degree Celsius. So, let us say there is T2 and T1 this is 100 and this is 50.

So, as per the thermo capillary effect there is going to be a flow of this bubble towards the 100 degree case because of lesser surface tension on the higher temperature side and if supposing if we were to use this bubble as a driving bubble for moving the flow across which you know for moving the flow across which the bubble has been spread okay. So, it may as well carry as a plug in the flow behind it thus creating low pressure everywhere it goes and letting the flow follow it and also on the other side pushing the flow out.

So, it becomes an inlet outlet micro micro pump so in this particular case for designing the equation we want to determine the driving force of the bubble surface tension values are provided so Sigma at the air water interface is 58.9 when okay so let me write it as a function of the temperature so Sigma at 100 degree Celsius is 58.9 Newton per meter and Sigma at the 50 degree Celsius mark is 67.91 Newton per meter.

So, these are the two different Sigma's which creates such a driving force and I would like to look at what is going to be the pressure difference okay at the two ends of the bubble.
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So, the pressure difference you must remember for the bubble to survive is represented as two sigma by r okay so at 100 degree n this Delta P becomes equal to twice times of Sigma 100 degree Celsius by r okay and at 50 degree Celsius side this Delta P becomes equal to again twice Sigma 50 degree Celsius by r so these are calculated as 58.9 divided by the radius it is a 50 micron radius capillary so the bubble size should also be 50 microns for the pumping to happen as the bubble moves forward.

So, it is 50×10^{-6} okay and similarly here this is $2 \times 67.91 / 50 \times 10^{-6}$ so these are the two different pressures which are there at both sides obviously this is a higher pressure and so it will push the bubble forward towards the low temperature. So, the total actuation force which will be there is again what is going to be the; let us say these are P1 and P2 so $\Delta P_2 - \Delta P_1$ times the total interfacial area of the bubble A.

And in this particular case we assume the the pressure to be perpendicular to the surface of the bubble let us say the pressure is coming you know and the contact angle is basically zero. So,

you can assume these to be somewhat flat at both the ends okay and so we can approximately take this to be the cross-sectional area and this is πr^2 of course. So, π times of radius being 25 microns 25×10^{-6} square.

So, when we compute this number here we get 0.9 micro Newton so this is about the force which will be needed to move a bubble through heating the bubble differentially on both ends which is again a non mechanical version of the actuation strategy that could be utilized for the purpose of this particular pump. So, I am going to close on here and probably start the next lecture with few more descriptions of different schematics of micro pumps as well as some fundamentals of gas sensors till until then thank you very much.