Micro Robotics

Prof. Palani Iyamperumal Anand

Department of Mechanical Engineering

Indian Institute of Technology, Indore

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Microsystems for Microrobots (Actuators) - Module 02

In the last class, we discussed the micro-pumps, the configuration of the micro pumps, the overall evolution of the micropump, and we also had some discussion about the overall characteristics of the micropump. So, what are the different sub-elements of a micro-pump that are available, and how are micro-pumps designed with reference to different configurations? We had some discussion about these modes, including the absorbing mode and the release mode, and then we also had some discussion about this valve and a valve-less pump, etc. Now, in today's lecture, we will discuss the other configurations of a micro-pump, and we will also discuss some of the case studies relevant to the micro-pump. So, as far as micro-pumps are concerned, we can appropriately classify this micro-pump based on the actuation domain. So, one such classification includes the electromagnetic micropump. So, as far as this electromagnetic micropump is concerned, as the name suggests, these electromagnetic or magnetic micropumps work on the principle of generating repulsive and attractive forces between the permanent magnet and drive coil.

Upon the application of electric current through the drive coil, which in turn oscillates the diaphragm or the membrane. So, ideally, we have two conditions. One is a kind of ideal condition; if you see the overall configuration of this, there is an embedded magnet in place, there is an inlet wall and an outlet wall that are available, and then, inside these embedded magnets in the ideal condition, there is going to be a flow. When we try to energize this magnet appropriately, we can have control over the diaphragm.

So, in the case of an inlet, this inlet valve opens, and appropriately, a kind of absorbing condition will occur, and then there will be an outlet valve that exists. So now, if we closely observe the overall actuation mediums or the actuation switch that has control over it, one is the drive coil and the other is a diaphragm that exists, which is going to be a kind of embedded magnet. So, here we have two conditions. One is a kind of ideal condition which is used for pumping, and then there is going to be a kind of condition where an absorbing condition will happen, where, through the absorption, the liquid is fed into it, and then we will have the release condition. In the case of a release condition, the outlet valve will open and the liquid will be pumped to the desired system appropriately.

Now, the next configuration we can consider is a simple rotary micropump. So, as far as these rotary micro pumps are concerned, they are kind of a dynamic micropump that works by adding kinetic energy directly to the fluid through moving boundaries or fields. So, these dynamic pumps maintain a continuous flow through momentum transfer, requiring a higher operational speed and precise fabrication tolerance. So, when we try to talk about the higher operational speed and precise fabrication tolerance, it basically depends on the inlet and then it basically depends on the outlet configuration. So, based on the direction of the rotation, we can appropriately have an inlet phase flowing through it, and then there will be an outlet phase that exhibits movement through this particular system.

So, this kind of rotary-based micropump is efficiently used for creating a certain amount of vacuum or a certain configuration in such a way that a kind of vacuum will be created, and then there will be a continuous movement or flow of the liquid from one region to another. So that is the reason these kinds of rotary pumps are called dynamic micropumps, and they provide a kind of kinetic energy directly through the fluid that is moving along the boundaries of the field. Now, let us discuss one more configuration which is called a thermo-pneumatic pump. As the name suggests, there is going to be a thermal system in place, and then there is going to be a pneumatic system exhibited here. Due to the variation in the thermal properties, there is going to be a displacement that exists.

So, in the case of thermo-pneumatic structures, a phase change actuation of the micropump works on the principle except for the medium that is used for the actuation. That is, there is going to be a kind of continuous thermal expansion and contraction of air or phase-changing material in the secondary chamber, which exerts a pressure onto the diaphragm, causing it to deflect or providing an indication for an appropriate vibration. So, in this particular aspect, if you see, we have two different conditions: one is called an ideal condition and the other one is called a dispensing condition. So, in the case of ideal conditions, if there is an air chamber with a pumping arrangement available, then there is going to be an inlet wall. Through the inlet wall, there is going to be absorption, and through the outlet wall, there is going to be dispersion.

So, this fluctuation between the inlet and the outlet wall is taken care of by the heating coil that is available. So, by supplying heat to it appropriately, a pumping behavior exists. Based on the pumping behavior, the inlet and outlet conditions can be displayed. So, in these particular aspects, there is going to be a drive coil, an air chamber, and a diaphragm arrangement with a pumping chamber. So, this dispensing condition in the case of a dispensing condition, these kinds of diaphragms are going to be efficiently used for deployment or for the release of the fluid appropriately.

So, in the case of these drive coils, if you try to closely observe the diaphragm's perspective point of view, that diaphragm gets actuated because of the thermal heating or the thermal dispersal. So, the diaphragms are appropriately selected. In several cases, such diaphragms, bimetallic base diaphragm structures, are deployed. In some cases, we might have a thin metallic sheet where the expansion and contraction of these metallic sheets are deployed. So, only key parameters that affect these particular diaphragms, which basically include the thermal conductivity and the specific heat capacity of the material, have a high influence on developing such kinds of diaphragm: thermal-based diaphragm, pneumatic-based diaphragm, or thermo-pneumatic-based diaphragm.

Now let us talk about shape memory alloys. So as far as these shape memory alloys are concerned, we have already had several discussions on shape memory alloys, whether it is in the form of a bulk phase or in the form of a thin film base. So as far as these shape memory alloys are concerned, the actuation of this micro pump through a shape memory alloy is either through thermal or sometimes it might be through magnetic force. So, when we consider a magnetic force instead of a shape memory alloy, we will be using a Heusler alloy. So, the main actuation medium for these Heusler alloys, when we try to supply a kind of cyclic loading, is a cyclic magnetic field.

Appropriately, there will be an expansion and contraction that occurs in these particular structures. So, as far as these actuations are concerned with a shape memory alloy. So, we have a kind of switching between the austenite behavior and the martensite behavior. So, based on the switching between the austenite behavior and the martensite behavior appropriately, there is going to be a kind of actuation that exists, and there will also be a kind of deflection that happens. So, when we closely observe or when we have control over this solid phase transition between the austenite phase and the martensite phase, it appropriately provides us with a kind of flexibility to move or to have control over the actuation behavior in this particular process.

That is, if you try to tune its temperature property, we can appropriately have control over the actuation behavior. Then, with reference to the strain perspective point of view, mechanical strain can be developed during this phase transition, which results in the deformation of the micropump membrane. So, in this micropump membrane, what happens is that we have a kind of shape memory alloy-based structure, and then, when we try to actuate it, this micropump membrane moves back and forth, and accordingly, there is going to be a deflection, which is exhibited, and from this deflection, we can have control over the suction and the relief. Basically, we can have control over the absorption condition and the dispensing condition. If you remember, we had discussed this concept called shape memory alloy bimorph.

In the case of shape memory alloy bimorph, we have seen that a shape memory alloy structure is integrated with a Kapton polyamide. So, the actuation happens in such a way

that one way of actuation is taken care of by the shape memory alloy and the return stroke is appropriately taken care of by the Kapton polyamide. So, what happens is that when the kapton polyamide takes care of the return stroke, the main level actuation is taken care of by the shape memory alloy. So, the kind of actuation frequency can be appropriately exhibited using this system. So, appropriately, we can have control over the actuation frequency as well as the actuation displacement.

So, ideally it is a kind of thermal-based system, and the phase transformation of this thermal-based system is taken into consideration, ok. Now, we can consider this; the next level of the system is called an electrostatic-based micropump. So, as far as these electrostatic-based micropumps are concerned, it is basically like we discussed these comb drive actuators, where there is going to be an electrostatic charge that is generated. From these electrostatic charges, it is expected that there will be a kind of resonant frequency that exhibits, or a kind of micron-level displacement that can be controlled by these electrostatic charges. So, as far as we see in these electrostatic charges, the force of attraction and repulsion generated between the electrodes actuates the flexible diaphragm.

So, upon application of electric potential across the electrodes attached to the membrane and the pump body, the generated electrostatic force causes the diaphragm to flux, causing a change in the chamber volume which increases and the pressure decreases, resulting in the flow of the fluid inside the chamber. So, if you closely observe the overall attracting force and the absorbing condition, there is a diaphragm in place; then there is an electrode in place, so we have an inlet wall and an outlet wall. So, through the inlet wall, we are trying to look into the pumping behavior, and the electrode is going to be actuated, and the diaphragm is going to be actuated into it. Now, in this particular process, what we have seen is that we have a diaphragm and then there is an electrode in place, and the electrode is deployed. So, in these regions, exactly the electrostatic charges are going to participate, and when these charges participate, it gives a kind of efficient flexibility for the movement of the electrode from position A to position B appropriately.

 The interesting part of these electrostatic charges is that you can generate a high frequency using this system, and then appropriately dispensing conditions can be deployed. Okay, so if you closely observe the overall subsystems of these electrostatic pumps, there is going to be an inlet arrangement, a valve arrangement, a diaphragm arrangement, and an electrode arrangement, so the application of this actuation of this electrode will help with appropriate movement. Now let us see some of the different configurations that exhibit the development of such a micropump with reference to different chamber configurations, which we saw when we looked into the classification perspective. So, with reference to the chamber configuration perspective, the micro pump is classified into two categories: one is called a single chamber configuration, and the other is called a double chamber

configuration, which is a kind of parallel connection. So, in the case of a single chamber configuration, there will be an inlet port and an outlet port.

We have a diaphragm in place that is integrated with the chamber. Through the inlet, the liquid is made to pass through it, and there is going to be an actuation that exists, and through this actuation, the outlet is made to feed into it. Whereas, with reference to the double chamber parallel connection perspective point of view, we have chamber-1 in place and chamber-2 in place. Liquid is fed into this inlet through chamber-1 and then flows. We have 2 inlets and 2 outlets, so there are 2 chambers placed here.

So, these two chambers will try to vibrate and then will try to oscillate at a higher frequency, and you get an outlet coming out of it. So, wherever you need to work on mixing fluids or when you want to work with two different types of fluids, such double-chamber-based parallel connections can be deployed. Now, this is a kind of configuration that we call a double chamber series connection. So, as far as this double chamber series connection is concerned, chamber 1 comprises a liquid, and then there is chamber 2, to which the liquid will be pumped. In the meantime, chamber 1 can again collect the liquid, and then it can move to chamber 2.

That is, for instance, if I want to disperse a particular fluid at a particular frequency or with a particular time interval, such double chamber-based series connection systems can be efficiently deployed for appropriate dispersion. Now this is a completely different configuration, where let us consider there are three chambers. The inlet is connected to chamber 1 and the outlet is connected to chamber 3. So, the pumping is happening in such a way that, through the inlet, the pumping is fed, and then it is passed through chamber 2. In chamber 2, what happens is that there is going to be a certain amount of mixing, and after this mixing, this system is made to push through chamber 3, and from chamber 3, you are trying to move to the outlet system.

So, what is happening is that from chamber 1, we are trying to collect the fluid, and then it is stored in chamber 2. Once again, through chamber 1, suction happens, and then it is made to pass through chamber 2. So, due to the variation in pressure difference between chamber 1 and chamber 2, the liquid available in chamber 2 will try to move to chamber 3. Unless a pressurized fluid is made to move to chamber 2, there will be a kind of flow through this outlet. So, in this case also, wherever we need to have a mixing of a fluid or wherever we need to have a different time delay, such kinds of peristaltic pumps can be deployed.

 Now let us see some of the different configurations or different types of valves that exhibit. So as far as valves are concerned, we have already seen a configuration with reference to a valved micropump and a valveless micropump. So, we have seen a comparison with

reference to the valve micropump and the valveless micropump. So, in the case of micropump valves, the flow rectification that converts the non-directional flow to a directional flow depends on closing pressure, response type, micropump efficiency, and material capability. So, as far as this particular case's perspective point of view, there is a ball valve arrangement where there is a flow direction.

Through this flow direction, we have a ball in place, and in the flow channel, there is going to be a no-flow direction through which the ball moves. So, the control of the flow or the movement of the overall pressurized fluid is well taken care of using this ball valve. Then there is a kind of dynamic geometry valve which exhibits. So, as far as this dynamic geometry valve is concerned, we can classify these dynamic geometry walls into two. One is called a bridge-type dynamic geometry valve.

Another one is called a cantilever-type dynamic geometry valve. In the case of a bridge-type check valve, there is going to be a slot-like arrangement. Wherever we need to have a no-flow direction, the bridge will move, and wherever we need to have a flow direction, the bridge will rotate. The same configurations or similar functionality can be deployed by a kind of cantilever-type configuration. So in the case of the cantilever type configuration, we will have a cantilever type of arrangement.

So this cantilever type can be used for the opening and closing of the valve. So, in this particular case, for example, if there is going to be high pressure and low pressure, the cantilever will appropriately open and close based on the requirements or the flow direction. Now there is a kind of configuration called a static geometry valve. As far as this static geometry valve is concerned, there is going to be a conical nozzle and a diffuser; there is going to be a nozzle action and a diffuser action. Within this nozzle action and diffuser action, two important parameters can be controlled: one is the flow and the other is the pressure difference.

So, as far as the flow perspective is concerned, by creating a pressure difference between the nozzle action and the diffusion action appropriately, we can have control over the flow, or by giving a different pressure difference appropriately, we can have control over the flow. Now, these kinds of geometric valves are basically classified based on the configuration or the type of geometry. So, based on the type of geometry, if you observe, we have a conical nozzle or a diffuser available. The nozzle action will work, and the diffuser action will work. So the flow moves appropriately between the nozzle action and the diffusion action.

Similarly, there is a kind of trapezoidal nozzle diffuser. So, as far as this trapezoidal nozzle diffuser is concerned, based on the overall geometry, we can appropriately have different flow control, or we have different diffusion control. So let me just take you around the different diaphragm materials and their overall properties. So as far as this diaphragm

material is concerned, this is a kind of static material that exhibits different diaphragm materials, which are nothing but actuation principles that exist. Now, if we try to consider a glass, the different materials which include the glass, the PDMS, the silicon wafer, the electropolymer, the stainless steel, brass, polyamide, rubbers, Nafion, and acrylic elastomers are being efficiently used.

As far as the actuation principle perspective is concerned, we have piezoelectric structures, electrostatic structures, an electromagnetic-based system, a thermo-pneumatic-based system, and phase change materials are also available. So, in addition to this, we have also seen this configuration of thermo-pneumatic structures and how it is being deployed. From a thickness perspective, in most cases it ranges from 0.01 to 0.4, which is the overall configuration, and these are some of the basic properties that these materials exhibit.

Now let us discuss one case study where a type of micropump is used for a microrobot in endoscopic-related applications. So, in this particular process, the overall thought process is something like this: suppose this is an intestinal wall. In this intestinal wall, there is a configuration. The main focus of this microrobot should be to move through this intestinal wall. Appropriate actuation needs to be deployed in this particular system.

So, the system looks something like this. This is a kind of former cabin, and this is going to be a kind of hind cabin, and there are two gas bags. Okay. So, this is going to create a kind of inchworm mechanism. As far as this particular case is concerned, one thing we may need to consider is that there is going to be a locomotion that it exhibits. In this locomotion, what we can see is that the fabricated micropump will be assembled in the hind cabin of the microrobot.

It will be kept over here. The front and back bags surrounding the outer surface of the microrobot will be inflated alternately to engage the clamping function. So another linear actuator will be assembled in the front cabin to facilitate the forward and backward movement. So the micro-robot can propel and bend itself to simulate inchworm-like movement. So, when the gas bag is inflating and clamping, we can like workout the clamping force and then the force which has evolved for flowing through the intestine. Now this is the overall structure or the final product of what is being imagined to move along the intestinal structure.

Now to make it proper, the system comprises a kind of linear actuator, an air drum, and a small one-way valve. So, few researchers have developed this type of medical micropump for an endoscopic robot that is driven by a kind of linear actuator based on a direct DC motor, and this micropump consists of two active one-way valves and a cylindrical air drum. So, ideally, the overall size of the pump prototype will be in the order of 12.5 mm in diameter and 56 mm in length. So, if you see the overall construction of it, here we will have a kind of linear actuator.

And then, we can have a kind of, probably I can draw like this: one-way valve, the air drum, and the linear actuator. So, the one-way valve comprises something like this, which has a kind of small gas bag arrangement, and then there is a rubber hose, which we call an air drum. This is a kind of bellow arrangement. This is connected to the linear actuator. So, this is a kind of linear actuator. So, what happens is that the overall arrangement, if you see the linear actuator, is meant to provide a kind of motion to the air drum, and this air drum will give a kind of inching mechanism. The overall locomotion occurs through this air drum. So, we are trying to actuate this gas bag. So, when these gas bags get actuated appropriately, we can have a kind of peristaltic motion in this particular air drum, and then the overall peristaltic motion is controlled by this linear actuator. So it gives forward motion to the structure, and finally, this kind of structure can be deployed to move into the overall intestine.

So what happens is there is going to be a kind of movement, a kind of inchworm movement that exhibits. So, if we see the overall parameters that are involved in it, we need to count the overall stress set on the intestinal canal by the gas system, as well as consider the overall configurations that include the The virtual work principle. So, when we try to consider the virtual work principle, the following parameters will come into consideration: let us consider M as the torque of the DC motor, F_d as the output force of the linear actuator, V as the linear speed of the linear actuator, and eta (η) as the transfer efficiency. So, ideally in such systems, we can achieve an actuation in the order of a few microns, and if you try to look at the overall design perspective, since it is used for biomedical-related applications, especially in the intestine where it is highly sensitive. Such an airbag arrangement will be highly helpful in providing an inchworm motion to the system so that we can have control over the structure.

$$\eta M\omega = F_d V$$

This is a kind of case study. you can refer to this paper to have a much better understanding of it .In fact, this system is quite interesting, where a kind of linear actuator and a one-way valve are appropriately designed, and it is used for the movement of the system. Now, as far as future perspectives are concerned, especially from the micropump perspective, there are many case studies that are well projected. In fact, from a biomedical perspective, a good number of micro pump developments are being established. Additionally ,from a space perspective, a good number of micropumps have also been established

When we try to look into the future direction and perspective, such as advanced materials and fabrications that can be efficiently deployed for developing this micropump. Smart and integrated systems can be focused on. Therefore, the system should focus on low power consumption since it has potential applications in biomedical-related fields, as demonstrated in one particular case study. Similarly, we can also focus on some of the other case studies, particularly those, so that you can have more flexibility for biomedical-related applications, and the most important aspect is with reference to lab-on-a-chip

integration. Now, to summarize from the perspective of micropumps, we have seen the different configurations of micropumps.

So, we have seen the overall evolution of the micropump. We have also discussed the different microfabrication techniques that have been employed for micropumps and the different materials that are being used for micropumps. So, different actuation modes. We have seen the different designs where various actuation modes are deployed to address micropump-related development, and we have also gone through some aspects where we have observed that these micropumps are used for different functional applications. So, we have also seen some kinds of parametric-related applications related to micropumps. In the next module in the next class, we will be discussing the micro-engines, the different configurations of micro-engines, the different actuations of micro-engines, and how these micro-engines are being deployed for different applications in detail.