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Week- 8

Lecture No- 38

Microsystems for Microrobots (Actuators) - Module 03

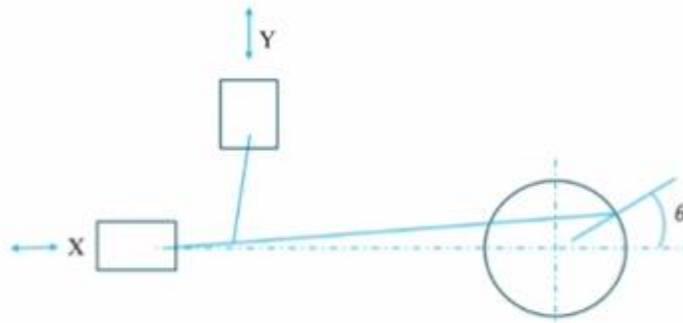
We will discuss micro-engines. Micro-engines are considered a kind of conventional actuator. They have potential applications in different fields. So, when we try to scale down these engines on a micro level, different complexities come into the picture. So, one of the complexities includes that, like in the conventional micro engine, there is going to be a combustion. However, when we try to scale it down for some application this combustion should be appropriately replaced by a certain mechanism. The second thing is actuation displacement and actuation frequency. Like in most of the engines of this type, actuation displacement and actuation frequency are slightly on the higher side. However, for a micron-level perspective, we may need to scale it down for a lower level, like a kind of stick-slip effect or a kind of theta orientation effect that needs to be appropriately translated. So, as far as these micro engines are concerned, these micro engines can be defined as a kind of micro-scale device that can convert various forms of energy.

Either it might be electrical energy, or it might be thermal energy, or it might be chemical energy that needs to be transformed into the form of mechanical work, or ideally it should be transformed into the form of motion. So, as far as these micro engines are concerned, these micro engines are miniaturized power-generating or motion-producing devices that operate at a micro scale. So, these devices typically range from a few micrometers to several millimeters in size and represent a convergence of mechanical engineering, material science, and microfabrication technology. Conventionally, if we try to investigate the mechanical representation of these micro engines, they are represented in this form. So, one has a translation node like this; either it has a movement in this direction, or it has a movement in that direction, and there is going to be a rotation.

This appropriate rotation will help in an appropriate translation in the x direction as well as in the y direction. So, symbolically, the representation of micro engines is represented like this. So that both the x-y plane and the theta plane are taken into consideration. Now, let us classify these micro engines. So, as far as these micro engines are concerned, So, these micro engines are classified into two categories. One is called a kind of with reference

to an energy source, and the other one is with reference to an operating principle. So, as far as these micro engines are concerned, they are a highly niche area with potential applications in different fields, such as swarm robotics and micro robotics. Some of the fields include a kind of micro energy generator. So, these are some of the fields where such kinds of micro engines can be deployed. Now, as discussed, when we try to classify it, we are trying to take two different classifications: one with reference to the energy source and another with reference to the operating principle.

From the perspective of energy sources, we have the classification in terms of electrostatic



Mechanical representation of a microengine.

micro engines and electromagnetic micro engines. Piezoelectric-based micro engines, thermal micro engines, chemical micro engines, and optical micro engines. So, as in the case of an energy source perspective, such as electrostatic, electromagnetic, and piezo. So, where we are trying to incorporate a certain amount of actuation principles, which are being deployed, and based on these actuation principles, appropriately these energy sources are being deployed. Now, with reference to the operational principle perspective, we have the optical-based system, the chemical-based system, and the thermal-based systems, which are being deployed appropriately.

Now let us take the first micro engine system, which is called an electrostatic micro engine. So, as far as electrostatics is concerned. So, we have discussed the fundamentals of electrostatic generation. So, in fact, we have taken an example of a comb drive actuator. So, these micro engines also work on the principle of this comb drive actuator. So as far as looking into the overall configuration of this, this is going to be a kind of fixed electrode. So, this fixed electrode says there is going to be a ground part, and this is going to be a cantilever beam electrode; this cantilever beam electrode is going to resonate at a vertical frequency. So appropriately, the ohmic contacts are being established. So, in these ohmic contacts, we have a voltage pad, and then there is a cantilever beam-based electrode that is being established over here, and there is a ground pad, and the fixed electrode is there. So, the cantilever beam electrode will try to move back and forth, and appropriately, we can achieve a kind of actuation that it exhibits.

So, from an operational principle perspective, there is a kind of Coulomb attraction and Coulomb repulsion that participates in generating the base principle for a certain amount of applications. Basically, it is a kind of actuation that exhibits reference to this charge device. So, when the voltage is applied, the electrostatic force generated causes a relative motion between the fixed and movable parts. So, in this case, let us take this example.

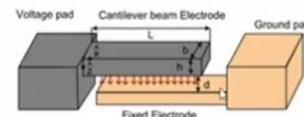
$$F = \epsilon A V^2 / 2 D^2.$$

F is the force; epsilon naught is the permittivity of free space. Ideally in most of these cases, it will be kind of a vacuum condition, or it might be in a controlled environment. And A is the electrode overlap area, V is the applied voltage, and D is the gap distance. So, some of the key advantages of these electrostatic micro engines are concerned. It has an advantage that includes low power consumption, a faster response time, and compatibility with standard microfabrication processes. Since there is already a well-established methodology with reference to the electrostatic charge perspective or with reference to the comb drive actuator perspective. Based on the appropriate displacement and frequency, we can have control over this overlapping region so that we can achieve the resonant frequency we are looking for. Now, as far as the application perspective or reference to field expertise is concerned. So, it is mainly meant for producing small forces, and it also requires high voltage operating conditions. Now, if we closely observe the design considerations, the key design considerations for the electrostatic microengine include electrode geometry optimization for the fourth generation, voltage requirements, and breakdown prevention.

Operate on the principle of Coulomb attraction and repulsion between charged surfaces
When voltage is applied, the electrostatic force generated causes relative motion between the fixed and movable parts.

$$F = (\epsilon_0 A V^2) / (2 d^2)$$

F force,
 ϵ_0 permittivity of free space,
 A electrode overlap area,
 V applied voltage,
 d gap distance.



Advantages include low power consumption, fast response times, and compatibility with standard microfabrication processes.

Generally, produce small forces and require high operating voltages

Mechanical spring design for restoring forces. So, as we have seen in the earlier case as well. So, this electrode geometry plays a vital role. So, based on the overall configuration or the overall application, we can have a kind of control over the electrode generation and

electrode geometry. Then, the voltage requirement is going to play a vital role. Ideally, it has direct relevance to power consumption as well as direct relevance to breakdown prevention. Then, we can also have a kind of mechanical sprint design for restoring the forces, and friction mitigation strategies can also be deployed appropriately. The most important aspect is that it has an integration with control power electronics, which can be deployed appropriately. These are some of the key aspects from an electrostatic perspective; electrostatics has very little focus and very limited applications, especially because it produces a very small force, and in most cases, these comb dryer actuators are well taken care of for different activities related to a certain amount of actuations. Now let us see the next type of micro engine, which we call an electromagnetic-based micro engine.

As far as this electromagnetic-based micro engine is concerned, as the name suggests, these electromagnetic micro engines utilize the interaction between the current-carrying conductor and the magnetic field to generate motion. Higher force output compared to electrostatic and electromagnetic engines faces challenges with respect to miniaturization, especially regarding magnetic components and heat generation from current flow. One good example of a practical application from the perspective of electromagnetic engines is the solenoid configurations. As far as this solenoid configuration is concerned, we have a kind of helical coil, and through this helical coil, an electromagnetic field is applied; this will help the solenoid move in a micron displacement order. So, in fact, the base electromagnetic micro engines are the solenoids, and there are a wide variety of combinations in using these solenoids for different displacements. So, if you try to classify this overall configuration of these solenoids, one configuration includes the planar spiral coil. In this planar spiral coil, we will have a core, and the coil will be placed here; this is the region where the magnetic field exists. So, this will act as your solenoid which moves in this orientation. Next is referred to as a helical coil orientation; in the case of helical coil orientation, this will be our core, and the current will be placed helically. and this will be the kind of a magnetic force which will exert for the moment.

Then we have this vertical mender coil; as far as this vertical mender coil is concerned, we have an arrangement something like this, where the magnetic field will be placed in this direction. So ideally, the solenoids are configured with this orientation, and the core will try to move within this orientation appropriately so that we can use it for magnetic motion-related applications. So here I am, the kind of electric current which is being deployed; ϕ is a kind of magnetic flux. So, based on the application, we can either go for a planar spiral coil or a helical coil orientation, or we can also go for a vertical minder coil. Now, let us see the overall fundamentals of these electromagnetic micro engines.

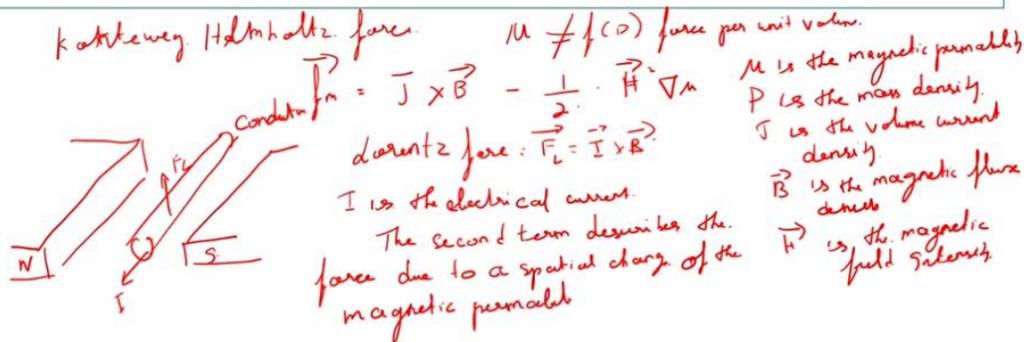
When we base it on the kind of fundamental. So, these electromagnetic micro engines are classified based on the principles under which these electromagnetic principles are classified, specifically the Lorentz force using a current-carrying conductor. The other one

is a kind of moving magnet approach. For the permanent magnet excited motor, the third one is a kind of variable reluctance principle. First let us discuss the Lorentz force motor. As far as this Lorentz force motor is concerned, the force density of a magnetic field is typically determined by a theory called Helms Kornberg and Helms-Mosk forces. So, that is force. So, basically in the case of an incompressible magnetizable medium, that is when μ naught is not a function of p , where that is force per unit volume, the f_m is given by $\mathbf{J} \cdot \mathbf{B} \frac{1}{2} \nabla \mu$. So, let us consider a kind of system where μ is the magnetic permeability, ρ is the mass density, \mathbf{J} is the volume current density, and \mathbf{B} is the magnetic flux density. and which is the intensity of the magnetic field.

Electromagnetic Microengines

MICROROBOTICS

- Lorentz force motors: Using current-carrying coils in external magnetic fields



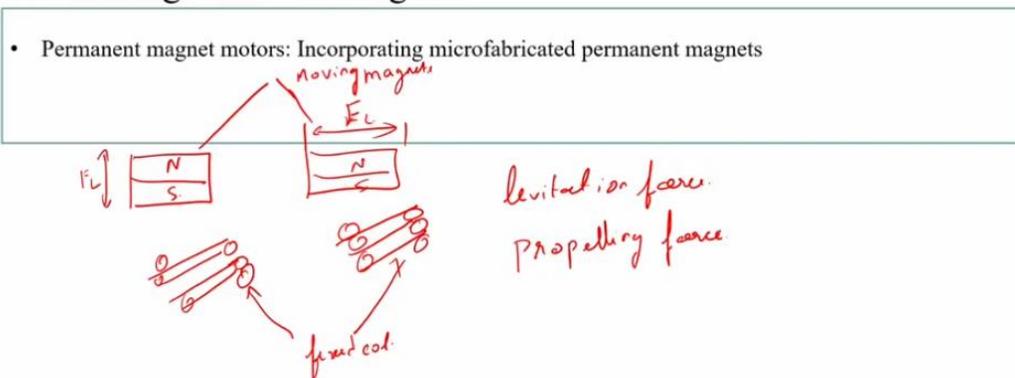
If you try to use the Lorentz force, let us take an example. Now, let us adopt the actual system. This is the magnet with the north pole, and this is the magnet with the south pole. We have a conductor in place, current I , and F_L ; this is going to be the conductor, okay. And then here, when we try to consider the first term, which corresponds to the Lorentz force, it can be represented as $\mathbf{I} \times \mathbf{B}$. I is the electrical current, and the second term describes the force due to a spatial change in the magnetic permeability. So, this is called a reluctance force. In case we consider it as a kind of compressible media, then we can call it a magnetostrictive force. Let us take the second concept, which is called a kind of permanent magnet based on a moving magnet approach for a permanent magnet excited motor; that is, it is a kind of incorporated microfabricated permanent magnet motor. If we see the overall configuration of it, let us consider two moving magnets: one north pole and one south pole.

These are the two fixed coils that are being placed, and these are the two moving magnets, which is represented by FL . So, in this case, this is a kind of electrodynamic actuation force that is based on the generation of the Lorentz force on the current-carrying conductor due to a magnetic field. So, in the case of a permanent magnet excited motor, the Lorentz force

results from the interaction of the permanent magnet with the magnetic field of a coil. So, the direction of the generator's electromagnetic force depends on the relative orientation of the motor's concept of the flux density of a permanent magnet and the direction of the electric current. So, the electrodynamic motor concepts enable force generation in two directions: one along the levitation force and the other along the propelling force. So, two design options are possible. So, the moving coil approach, where there is a fixed magnet, exists, and then there is a kind of moving magnet approach, where there is a fixed coil. So, like that, we can have two different options. Now, let us discuss the variable reluctance motor. So, in the case of a variable reluctance motor, The variable reluctance motor principle is based on the generation of force due to a minimization of the magnetic reluctance. So, let us consider the reluctance force from the interaction with the surface.

Electromagnetic Microengines

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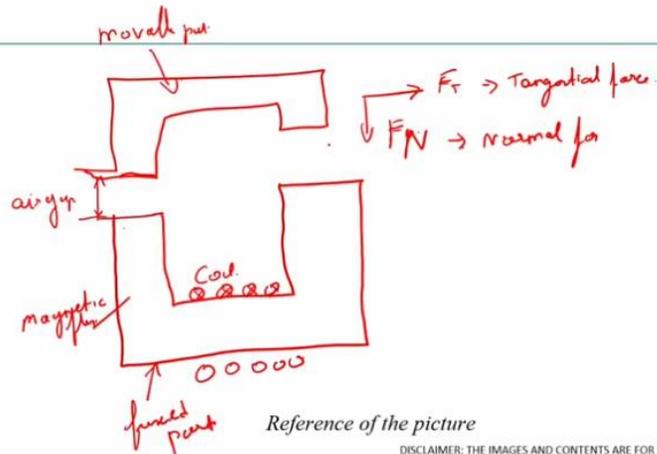
Let us consider a configuration. This is a kind of movable part. So let us nominate it as F_t and F_n a magnetic flux, and this is the fixed part, and this is a kind of coil which is established over here, and then we have a movable part in place. So F_n is the normal force, and F_t is considered to be the tangential force. So in principle, the normal forces are much larger than the tangential forces, which cause a kind of linear or rotary movement. These aspects need to be handled carefully in the design of such a variable reluctance micromotor. Because these kinds of variable reluctance micro motors are concerned. So, the concept has a single gap that suffers from highly additional friction caused by the drive itself. So, this is a kind of arrangement that is being established. So, as far as this particular case is concerned. The overall fabrication is going to be a major challenge. So, the fabrication can be appropriately applied by giving appropriate confined to the system which has a direct relevance towards different applications. These are some examples with reference to an electromagnetic perspective. Now, let us discuss the piezoelectric micro engines. So, as far as these piezoelectric micro engines are concerned, So, these piezoelectric microengines harness the mechanical deformation of a piezoelectric material under an applied electric

field. So, these engines can produce a highly precise high-frequency motion with a relatively low voltage requirement, and some of the common designs include basically the ultrasonic motor, which uses a kind of traveling or standing wave in the case of a piezoelectric element.

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Variable reluctance motors: Exploiting changes in magnetic circuit reluctance



Reference of the picture

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It also has a kind of inchworm-related configuration that is used for employing a kind of sequential clamping and extension of a piezoelectric motor. So, as far as these piezoelectric motors are concerned, they are widely used for micropositioning-related applications, such as micro-manipulation and precision positioning, etc. In those conditions, such kinds of piezoelectric-based micro engines can be deployed; however, one of the major aspects is that it faces limitations with reference to power output and stroke length. However, these piezoelectric microengines can be appropriately implemented by deploying a certain amount of mechanisms, and with these mechanisms, we can use them for different functional applications. So, we will discuss some of the configurations of these piezoelectric micro engines in detail in the upcoming classes. Thank you.