Design of Mechatronic Systems
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Lecture No 48
Case study: Hele-Shaw system for novel fabrication

So, in the last lecture, we were looking at a case study about micro printers in 3D micro fabrication and some kind of technology for that and how mechatronics very elegantly helped us to realize that the goals of that 3D printer. So, today we are introducing some other case study, where we are looking at this Hele-Shaw based system for very interesting way of fabrication.

So, this is again invention at our lab, this . And with some patents pending on this technology also. So, I will tell you why we are looking at these technologies and what are the utilities for some applications as we go along.

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So, let us begin with the, so, this is the lab, where this activity was carried out and we have seen here some of these micro 3D printing components that we have seen in the last class. So, there is a lot of collaborative work going on in this lab with different different places and maybe I will have some opportunity to talk about a little bit about that also.

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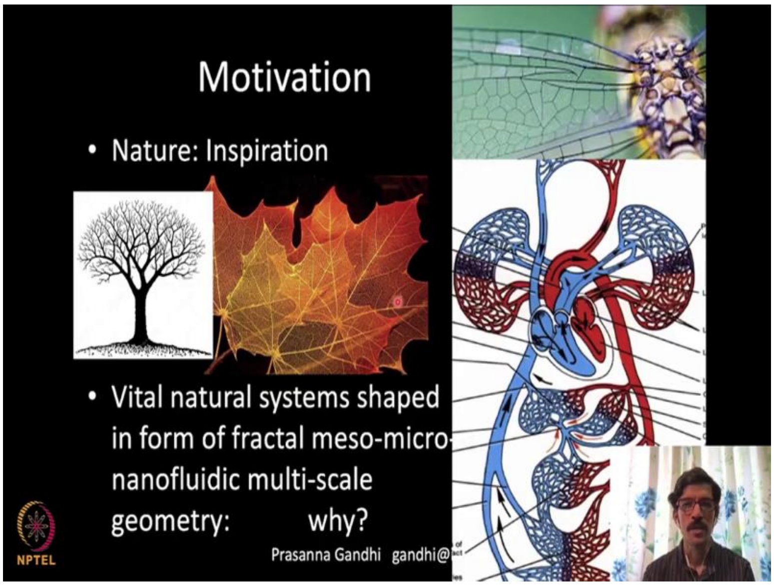

So, why we thought of like getting this new way of fabrication is based basically the inspiration is nature. So, in nature a lot of systems you can see have these branches, which are splitting branches. So, trees has like this main branch split into some branches, in further they split into branches further they split into branches. And this is there is some reason for such kind of structures, if you see the mass transport activity or the heat transfer activity, these activities are very very efficiently done by these kind of structures.

Say for example, in our heart circulatory system also, we have these branches, multiple branches and then split happens here and that is where the oxygen and carbon dioxide exchange happens for the lungs. And then again, these are brought back into some big size veins to the heart for pumping.

And this pumping action, whatever kind of energy that is required for these kind of structures is quite of some somewhat optimized a kind of pumping energy. So, the nature has some ways to optimize this energy requirements for such applications by having geometry for the structures in the way it is there in the nature. So, we are saying thinking like know this okay, how can we fabricate such systems.

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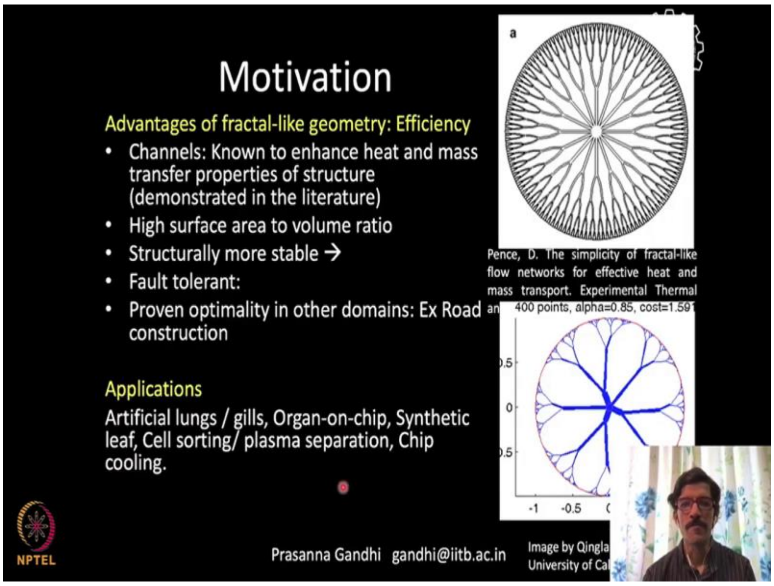

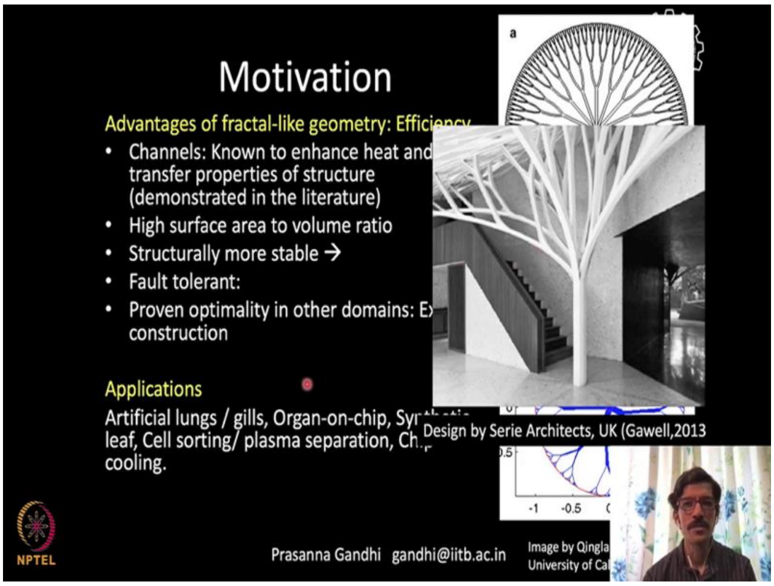

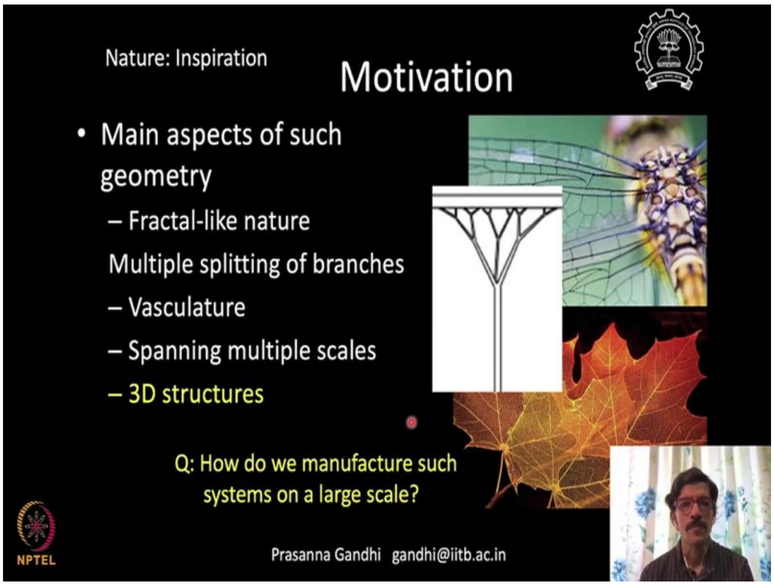

So, this have very high efficiencies as I was mentioning here. So, people have started like fabricating this in a lab scale by on a wafer on a silicon wafer to do the similar study and then they have found that okay, it indeed this is kind of giving you efficient kind of a heat transport with a minimum energy of pumping of the fluid into these channels.

These also have been found to be structurally more stable. If you see the tree structures, they are kind of stable structures for different wind and other kind of loading that is coming and people have started like using that also in a structural domain, the civil construction kind of a domain, where you have this multiple branch splitting happening to support the ceiling or some other thing.

So, you can see there are this more of such kind of a designs people have, they are also elegant in their artistic kind of a perspective. So, these designs have been coming up and they are now because of the 3D printing, which is pretty ubiquitous now, I mean and in the future also this is the way to go. You can print these kind of complex structures very easily. Otherwise without 3D printing fabric things such a kind of structure is quite a task actually.

So, there are some advantages to these structures and then the question comes, why we how do we kind of manufacture such structures in a very easy way? Conventional manufacturing techniques are there, but now we will see some different way of doing things here, but at not at this structure kind of a big scale, but as I say leap scale or some smaller scale than that. And then, we will see how this, some of the natural processes, which are there can be exploited to do a good control over these structures and how Mechatronics can play a very nice role in whole process that is how we are going to develop this talk.

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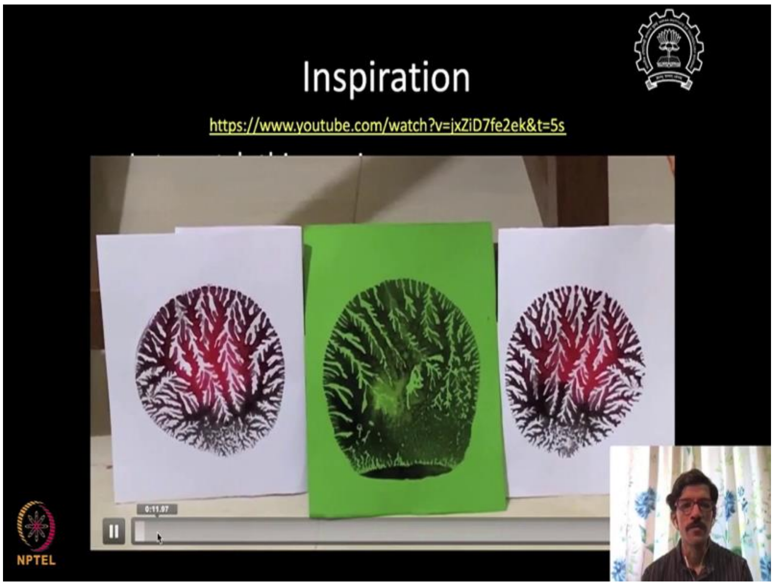

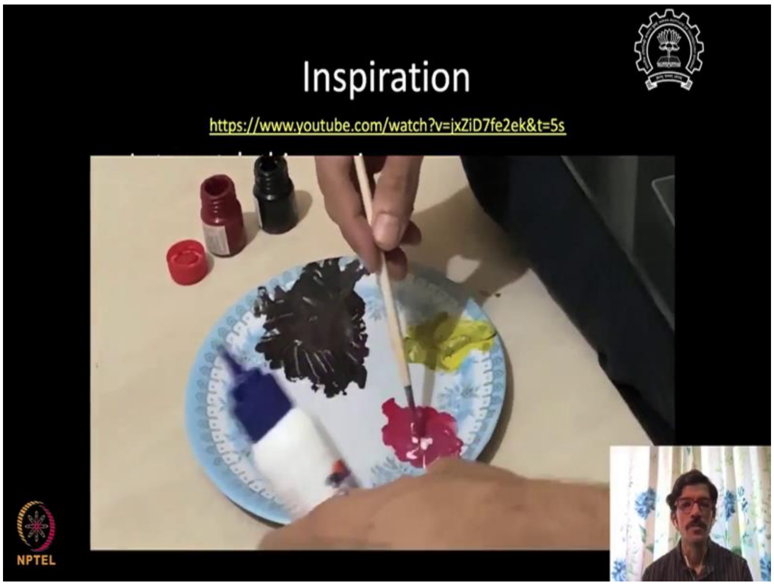

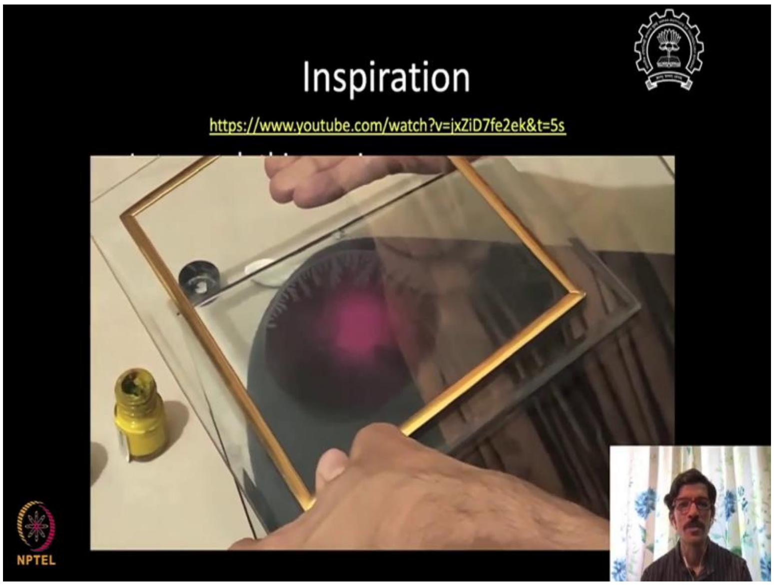

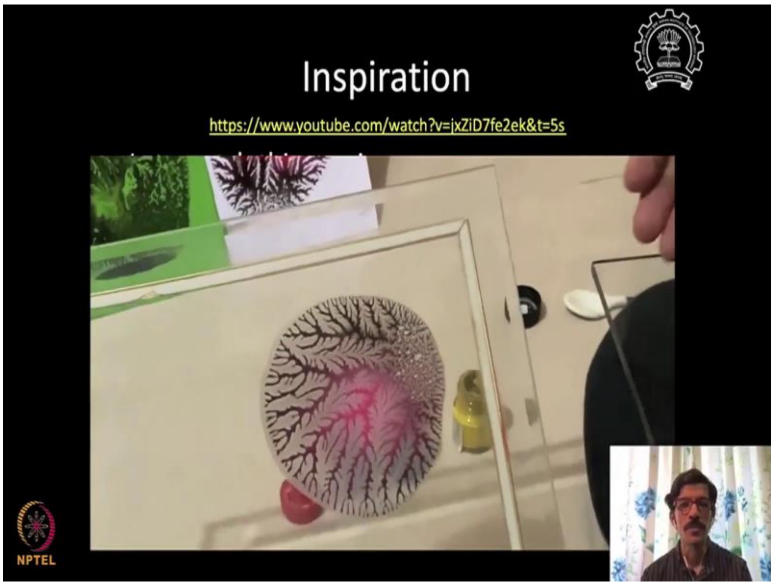
Inspiration
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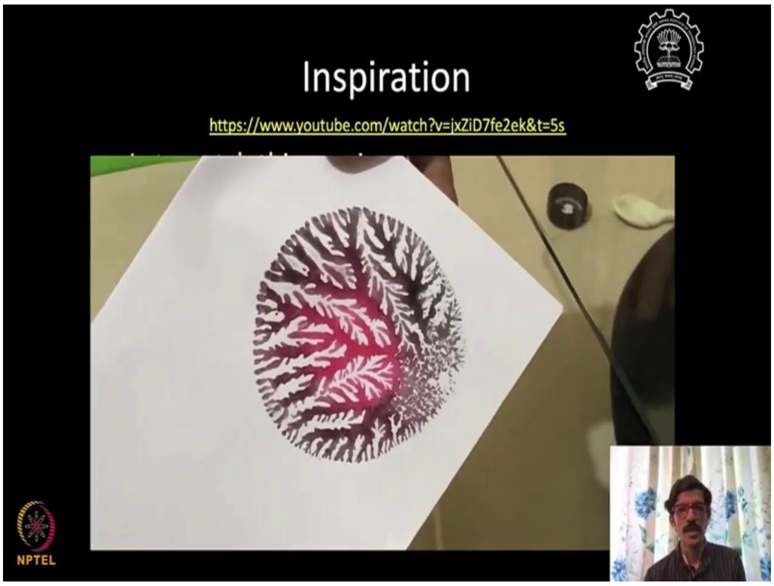
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So, if you see this the inspiration is really from the natural phenomena. So, you can see this video where like, you have this kind of a patterns that are coming in some kind of way of painting like how this course is you start off with this color palette here and then in the you have different colors you take to mix and like produce something and you add this glue to those colors, you put some kind of a fevicol or some other kind of glue and then like you make this slurry little thicker and use that on a plate whatever combination of colors that you want to color use, you may be able to use them and then you start placing another kind of a glass plate on the top of that.

So, to squeeze these two things in between the two glass plates. So, you see that that liquid is now pressed and it is formed into a film. So, you can see this somewhat circular film coming up there of the liquid color and fevicol that we have used. And then you simply separate these plates out. When you separate them out, you see this geometry starts coming out, some geometry starts coming is a fingering instability that happens called Saffman-Taylor instability, and this kind of a geometry that is coming up on this thing that you can transfer to the paper.

So, that is how like, you can get very interesting pictures of these kind. And so, this is how it is getting transferred to the paper from the glass and you have some interesting geometry coming up there. So, it is completely natural kind of way of doing things.

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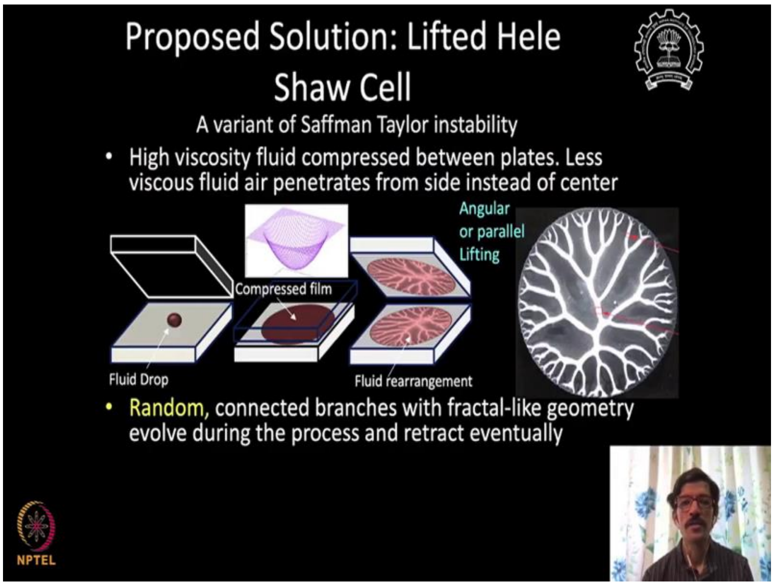

So, now, the idea here is to exploit this process called Saffman-Taylor instability in this cell called lifted Hele-Shaw cell for fabricating some interesting kind of structures of branch kind of a pattern. So, you understood the process that okay you have a fluid drop which is placed between the two plates and then this is compressed and then we separate it out. Now, instead of doing manually, we want to do it of course in some kind of a controlled fashion and for that we now need to design a mechatronics system to carry out that operation. And what patterns right now evolve are kind of random branches here, every time you do the process, you may not be guaranteed that okay same pattern will come.

In fact, the patterns will be completely different every time you carry out that. Now, we want to see that, these patterns are repeatable, controlled in some way and we want to know like know, how do we execute this process with the mechatronics. So, like that we will proceed two kind of seek answers to these questions.

So, you also gave a thought to this process maybe you think now based on whatever you understood from the course you see okay I suppose I want to carry out this what kind of thinking I should do or, so I would suggest you pause this video here and you know, give your own kind of design of mechatronic system around this kind of phenomena and see what comes to your mind. And see then like now when you see the solution some other things we may open up.

So, do that exercise it will be very important to do. So, you have to see the questions like how do we do this process of squeezing and then opening up either like the angular kind of a way of opening up or straight parallel way of opening up. So, this right now, we have done whatever you saw in the video is angular way of opening up.

So, how do we kind of carry out this repeatedly in the exactly same manner? You think about what is the process or what is the kind of mechanism, what are the actuators that we should use? What are the sensors that we should use? And how do we control, what is the control algorithm that you may have to think about? So, all these details, you give a good thought to that and then like now, we will see the solution. So, now I am proceeding. You may pause and think and then come back.

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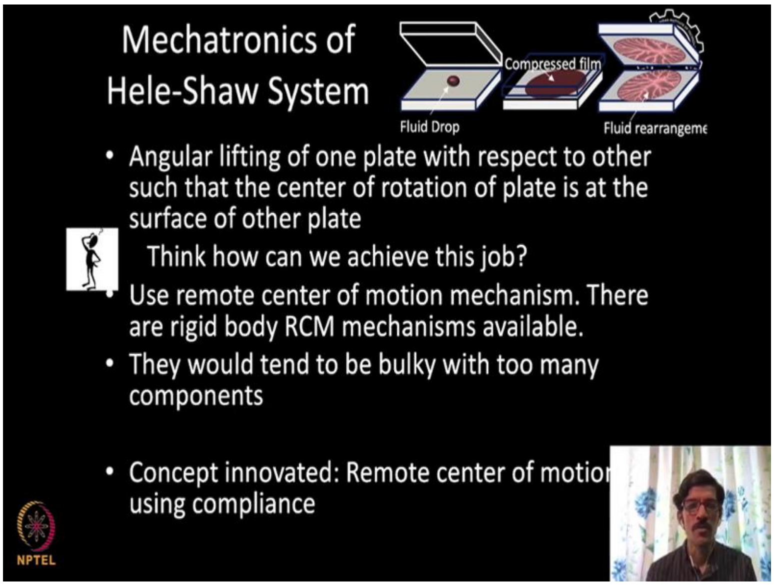

So, let us think about this Mechatronics now. So, your process is clear that okay, you have this fluid drop, now it is getting compressed and you are separating the plates angularly and this the separation of these plates happening angularly is about some axis which is fixed axis and preferably it is at the surface of this other plate. So, that the action happens really really nicely.

So, this is what is your constraint from the design perspective that, we want to open up these two plates and this opening needs to happen such that one plate is as if it is hinged to the other plate, we do not have a physical hinge there. We have this glass plates here and in the glass, you know how, you cannot produce you the hinge very easily and repeatedly.

And also, this process to have a good control like this needs to be carried out very very slow. This opening happens at a very very slow speed we want to open it up, we do not want to kind of do it at very fast speed. So, to have that control, these are like some design requirements you can bring out. As you do the process you will find that okay, these are the important design requirements that okay you need to move it very slow and then we need to have this motion happening such that there is no like the slipping motion, is only like opening motion happening.

There is no sideways motion happening or shear motion happening. So, again think about this part, if you have not really thought about this before. Then what we do is to use this remote central motion mechanism. So, there are many different remote central mechanisms that are available in the rigid domain rigid body domain you check out in their website and see what are different kinds of rigid body remote center of motion mechanisms available and one can employ them here for this process, the which will work for this process well.

But to move it move things at slow speeds we will have a joint friction. The friction in the joints of this RCM mechanism rigid body RCM mechanism and if you want to move slow with the friction it is very very tough to do you know that, right? We have seen that the friction model like, when you start, you want to move something which is very very slow speed. It does not the things does not move, they will just slip and then again you stop and again some force exceeds, then like you know it again slips like that in the sticks slip kind of a phenomena will happen if you want to move very very slow speed.

So, that is that is a problem with the friction. So, now how do we overcome this problem? So, then again, like we have seen if you want to have very accurate motions without friction, you need to think about these motions without having this rigid mechanical joints. So, without joints if you want to have this motion, the option you remember what we have seen in the class is the complaint mechanisms. So, flexure mechanisms is what you will think of using and then you need to kind of say okay, oh look, are there any compliant mechanisms, which can do this job available in the literature, then you may find some things you may plan and use that.

So, we have designed in this case, our own compliant mechanisms here. So, you will see in a minute how we have done that. So, this is how you start this process of, design of these kind of mechatronic systems in by using some of the ideas and concepts that we have learned in the course. So, we want to get this very slow motion and then that is why we are using this complaint mechanisms in the system and then we will now use this first see the complaint mechanism and then build system around that.

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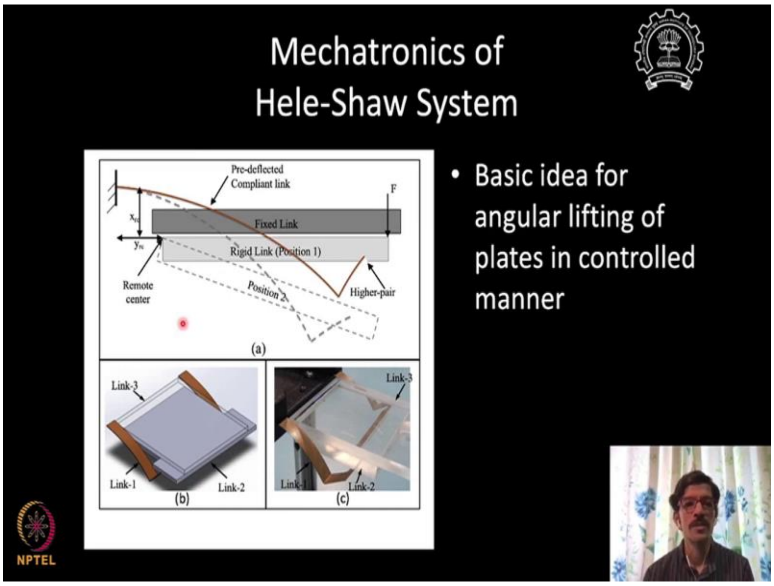

So, this is a complaint mechanism is very simple, it is like a simple cantilever link with this kind of a perpendicular fold to that link here and that is used as a compliant mechanism for this remote central motion. So, if you do the analysis of such a beam when the force is acting on it by using some standard softwares which are available in the market Ansys or Solidworks some FEM software's then you will find that this mechanism, we did not do that before we just like conceived this idea that, let us say if we can use a cantilever for this purpose and then we started playing around and then we found that, it is possible that this is this can be used.

Because, if you do this analysis, you find that there is a point which is not really the hinge point of this cantilever which is somewhere outside in the space around that point actually the motion happens as if it the endpoint of this compliant link is moving around a circular arc about the center. So, that is what you will see some literature also like some indications are there of such a kind of a thing. But there is in the literature it is only for the cantilever, but we are using now cantilever and some kind of a additional link which is this is fold of the cantilever basically.

So, this particular kind of mechanism has now we can call is not just a beam, but it is a mechanism has this remote center for motion and we used two such beams on the two different sides of this glass plate and use that to really do the job. So, this is like a solid model for that kind of design and then this is actually fabricated stuff, there are glass plates, there is a cantilever beam which is fixed at some point.

And we now arrange this entire kind of fixed plate and moving plate in such a way that the hinge is at the surface of the fixed plate. So, when I apply some force on this cantilever, automatically this plate is going to move as if it has a hinge here, because it is supported now by this compliant mechanism here.

So, of course, there may be some touch will be happening here. It is not like this is not touching the fix plate when the force is applied here, there will be touch up this point happening to the fix plate, but it will as you carry out this motion it will get lifted as if it is hinged at this point.

And we have characterized this by under by seeing under microscope, how much is there any motion happening at this point or not? All those things have been characterized to confirm that okay, it indeed moves as if there is a hinge at this point, although there is no physical hinge.

So, this is how we have built one part of the mechatronic systems in the Mechanical Plant so to say. Then now we want to see, where or how do we place the actuators and other kind of stuff in the system.

So, we need to see now actuator and then the actuator needs to get guided in some kind of straight line fashion and then, so that then we will be able to programmatically do the lifting process. So, you can see here that this lifting process is happening when this point is applied some force and this point like is to move in some kind of a straight line fashion then how do we achieve that.

We want just a motion below, we in some kind of vertical direction at this point. As a plate moves, there is a some small because this is a circular arc, this point is also going to go shift in the y direction also little bit. So, we need to have that some kind of a leeway for this point to move in the y direction, but we are to apply the force in the vertical direction.

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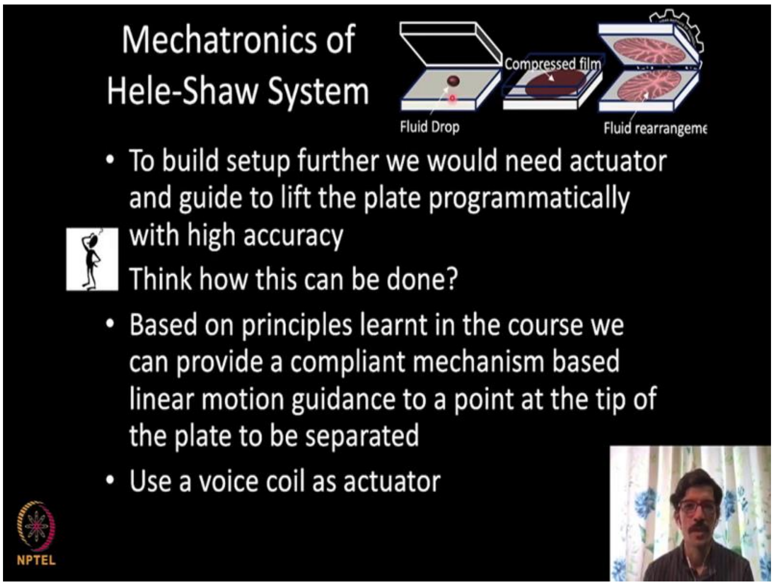

And for that we can use some straight line guide for this point to move. So, this is a straight line guide that is needed and again we want this straight line guide to have we can use some kind of ball bearing for the straight line guide that also may work. But we are using another kind of a compliant mechanisms to reduce friction in the system and this compliant mechanism is based on this some kind of a spiral grooves in a small disc that kind of compliant mechanism is what we are using here. That will avoid just a friction in the bearing But I think there is no harm like know, one can use directly some kind of a linear guide bearing and this job will be done no problem.

In fact, we are doing that in the case of our other setups, some other setups as well, they are using some kind of a lead screw or ball screw kind of arrangement to get these kind of precision motion. So, no problem. So, we are using compliant mechanisms as I said and then this compliant mechanism will be operated by the voice coil actuator. So, one can have a ball screw and the linear motor kind of a combination, not linear motion, the ball screw and motor kind of a combination to give you a linear motion.

So, the motor is rotating with the ball screw and you get some kind of a linear motion at the output which can be used to photo actuate this plate in the angular fashion and you or maybe the linear fashion as well. So, this is how like we now think of like actuating the system and the sensors in the system can be our standard linear encoders where we can measure the linear displacement of the actuator and conclude about the angle of the lift.

Because here now, we do not have really a shaft on which we can mount the sensor here, but the rotary motion measurement. So, we can measure the linear motion of a point which is getting actuated and conclude about the angular motion of the two plates.

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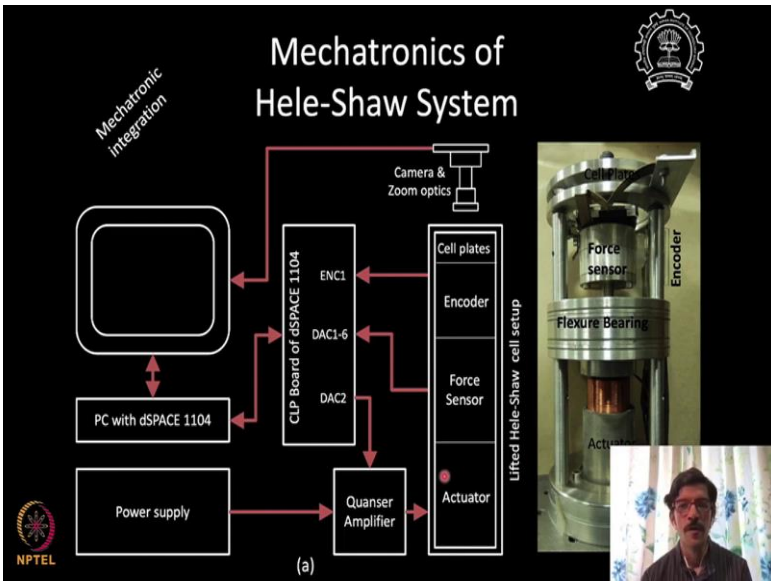

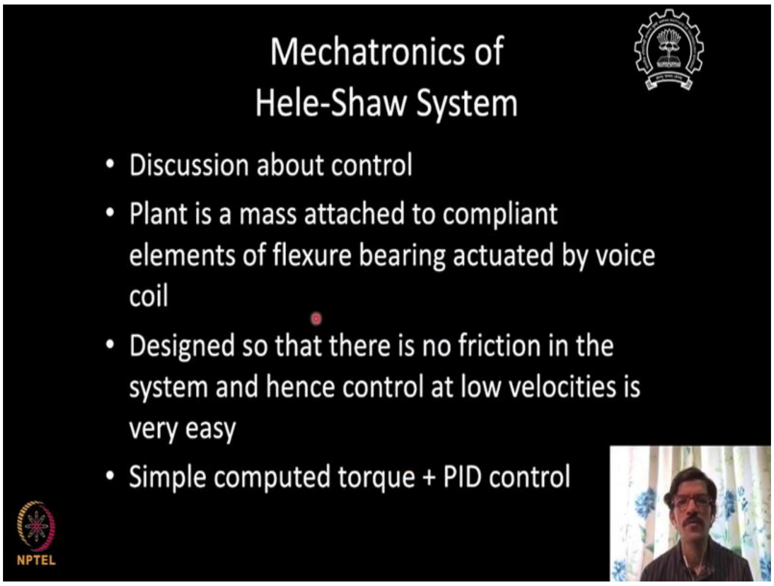

So, this is how now we put together all the parts in the mechatronic system. So, you have this complaint mechanisms you can see here. So, that is fabricated and it is in place for actuation, then we are actually using also the force sensor to measure the force. So, this was the first time we are doing this process. So, we wanted to have entire characterization of this process to happen and for that you need this force measurement to be done.

So, this force sensor six axis force sensor a load cell was used here between the plate and the actuator. So, you have this actuator up here, where this is a coil and then there is a magnet here and then this is a compliant bearing or flexure bearing which is used to just to guide the block up and down.

Now, so you can see the schematic up here. Now, how do you take encoder input into? So, we are using this controller as again a dSPACE controller system here, you can use also like other embedded systems like you can have a tiva microcontroller to be used and is fine no problem. So, what we are using here is encoder to sense the position of this system then four sensor input is taken by analog to digital converter. So, this should be ADC here. So, this is the ADC analog to digital conversion is happening here and that data is in your microcontroller and then this is digital analog converter is used to give input to this amplifier which will actuate the actuator.

So, it will flow some current in the coil and then it will actuate the coil. So, this is how like this entire system can be having this closed loop. So, you can close the loop based on the encoder data you can also based on the force sensor data we can close a loop. So, we want to say maintain a constant force that is possible with this closed loop system here. And then you of course use this camera and zoom optics to kind of observe what is happening to the fluid and see all this detail. So, this is how like we put together the entire Mechatronics system as a lab setup kind of a scale.

So, see again to tell you that, if you want these to be like a product out, then we replace these by using our microcontroller system with some small human machine interface to operate, operate thing. So, that is how like you know, our Mechatronics system will go as a product in this case.

Now, let us discuss a little bit about control what kind of a thing that you see if after seeing this system here, what kind of thoughts you can gather for really exercising control over the system. So, we want to basically move this upper plate in a very much controlled fashion to pull it the down to execute our process. So, we want to say, we want to maintain some fixed velocity as we pull it down. So, if this plate is pulled down, we want to maintain a fixed velocity say five micron per second or ten micron per second kind of velocity needs to be maintained.

So, that we slowly kind of do this process and observe things and we should, so this may not be as slow as all the time, but we have some provision to change the speed and we say okay, no, I do not want to now do it at like fifty micron per second kind of speed. So, I have a little faster process and then I observed. So, this is what is needed in the research to kind of change parameters and observe the things and then like you start studying the processes and conclude about like know what is your observation and how the theory will match with your experimental findings and things like that.

That is how you carry out those processes. So, in this case, now, your plant is this mass attach to the compliant elements of this pressure bearing. So, these are, so you have a force sensor also is a part of your mass and then your plate and things also are part of a mass. But interestingly here, so it is just a inertia that is there or there is something more to that.

So, we are when we are operating by this actuator it is just the inertia of these elements that is coming picture or there is something more to that. See of course, the liquid that is getting squeezed is going to apply some forces. So, do we know those forces, those are kind of like questions will come to mind to see, so that if I want to design control, that control should be robust to these forces. Otherwise, I design some control action and against are some chosen gains. But moment like these liquid separation force starts coming in picture when I start separating, then like this controller will start giving error.

It will not move the system anymore at ten micron per second kind of speed that I had desired to move. So, those kinds of things are going to happen. So, this is going to be like some kind of a disturbance rejection kind of a control you need to have. Because you do not know a priori what kind of fluid force is going to come. It will change from fluid to fluid and from experience to experience also there might be some small changes that will be happening.

So, that is where the feedback concept comes into picture very handy. See, we have design other point is like this, we have designed the system, so that there is no friction in the system. So, then control at low velocities will be relatively easy. The fluid is giving some friction, but that fluid friction force is usually as a viscous friction force. It is not a coulomb friction kind of a force.

So, that is why like you will not find the stick slip behavior offered because of the presence of the fluid, this and we are avoiding the stick slip behavior, because the two solid components rubbing against each other that kind of a coulomb friction we are avoiding by using the complaint mechanisms in the design.

So, this is a kind of a way we can see that the concept of design in mechanical domain which will ease out some parting control or some part in the electronics domain has happened here.

So, the way we did the same thing for the 3D printer case or you observe the similar kind of ideas in CD ROM drive, these are the kind of ideas that are to be employed to make sure that you are giving a complete system solution, not in mechanical domain separately and in the electronics domain separately. This is how we will think about in the, as application of the concepts that we learned in this course in the practical interesting kind of a system example.

And these ideas can be borrowed to many other systems that you say in your future activities, wherever you are kind of going, you will have an opportunity to work on such a systems and then you can give some elegant solutions to your problems. And of course, you can contact us any time if you are in need of such kind of solutions.

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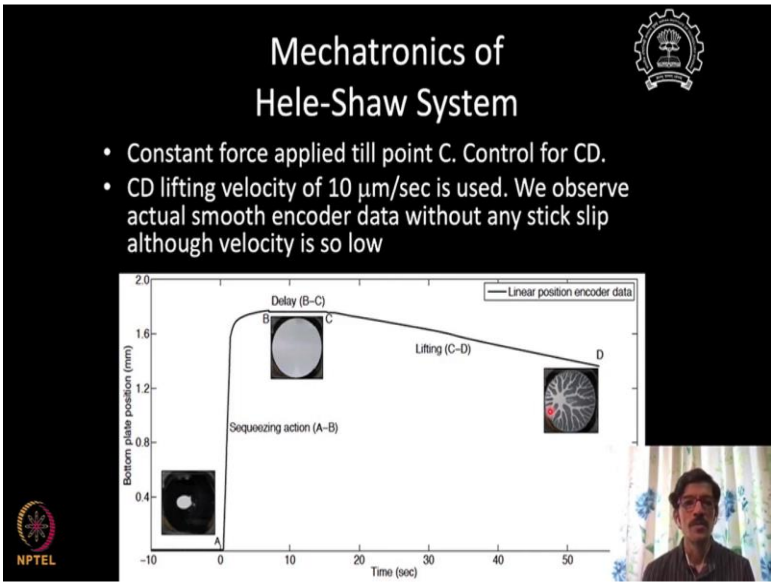

Then this we see the know the some of the results of the control. So, a control is done in a way that while squeezing we are squeezing from this point A to point B. So, this is a displacement or the plate position in mm kind of displacement of the point of the end. So, we are not plotting the angle here we are plotting the point of the motion of the actuator. Actuator moves the squeezing happens and like you will get this point here, this displacement of the endpoint here.

So, you squeeze it and then the squeezing happens with a constant force. So, we have programmed the thing such that we squeeze at a constant force, so that this squeezing happens, we do not worry about the displacement at that point. But only while separating, so then there is some delay for the fluid to get relaxed.

So, we provide some delay for the fluid to get relaxed and at C, point C the control is switched on. And this control is simple PD kind of a control is there PD PID kind of control is there that is switched on two kind of get the lifting done here. So, the lifting is shown in the bottom side motion or the bottom or downward motion of the thing. Upward motion is squeezing and downward motion is lifting or separation.

So, this is how we design the plan for the experience. So, if you see what is happening to the free droplets? Free droplet is between the plates, it is not yet squeezed from A to B it will get squeezed and you will form a like a film of the fluid. And then from C to D, the separation happens and you get this kind of a patterns that are produced on the surface.

So, these patterns are what we are interested into to study like how these patterns can be evolved with the control way and how these patterns can give us some application kind of a structure. So, say for example, these structures if I like take and solidify, they are liquid to begin with I solidify by some means and if I solidify then they can be acting as a micro channels for studying like the microfluidic kind of a processes which are similar to what they are there in the biological systems.

So, we can bio mimic the some of the devices or some of the organs that are there in the biological domain. So, this is a very interesting way of mimicking you know, what is there in our nature many different systems are there. Those systems can be mimicked and they can be studied and after studying like we can make use of them in the application.

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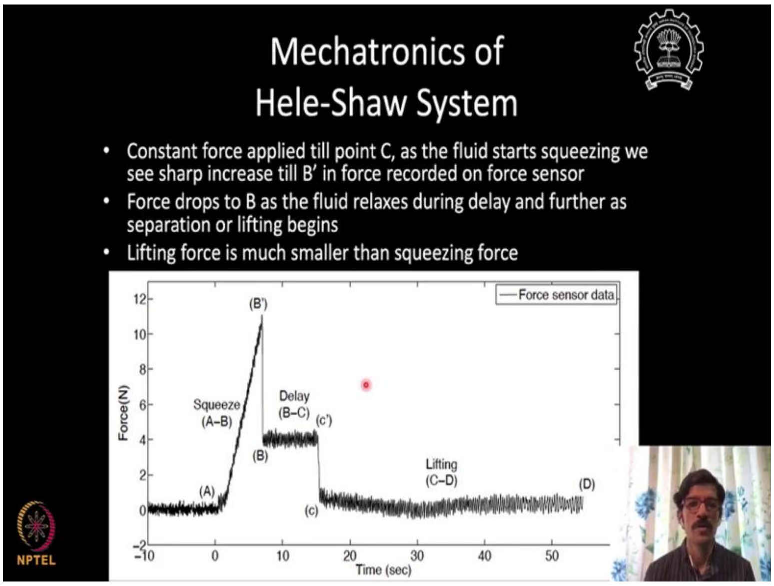

So, let us see the say when this you carry out this process, we will see now what happens to the force because we are recording the data on the force sensor we can look at that data. So, you see this data is coming as a analog force sensor. So, this data is a little bit noisy. This, I think this is after filtering further, so we have used some kind of a moving average filter to filter out the data and remove the, some of the noise but still like you can see some noise will be still there.

Because the analog sensors are prone to pick up noise from the from many environmental places as we have seen and we need to employ some kind of filters to filter out that noise making sure that your data that you want to preserve or you want to look at the data frequency and the filter frequencies are not messed up in some way.

They sense like you are as we have seen in the previous lectures, the filtering is done at much higher frequency than what data we want to look at. See these high frequency data is what is not what we want to look at. What we want to look at is okay what is this low frequency stuff that is coming up as we carry out this process? So that is where like you filter out like this very high frequency data. And it has been filtered out and it has gone down a little bit and but you cannot have it completely zero.

Now, so when we start squeezing this force starts increasing. So, this force increases up to point about eleven Newton force. And then we stopped squeezing, then that fluid relaxes and the force comes down to about four Newton. So, this is a delay part. And now we start, like giving a control to separate it out. Then force further drops and then it becomes to some level here and then like we are carrying out the separation in this domain.

At some point, the force will also see, you will see that force may go a little bit below zero also. So, that is how you read this graph and like conclude about what is happening in the fluids. So, about like maybe halfway through the process, you will find this force has gone down like the force is below zero.

You are actually pulling the liquid out or creating some kind of a vacuum inside the liquid or pressure that is lower than atmosphere inside the liquid. And overall, like you can see that the lifting force is much smaller than the squeezing force that is like a very important conclusion that we got from this process. So, that when we want to scale the process up two kind of much larger kind of dimensions, we need to be worried about how do we squeeze because we our actuator design will be based on this force.

So, we are able to kind of squeeze more than like you want to squeeze more than our thinner kind of a film, we need much kind of a higher actuation force there. So, these are different kind of domain of analysis saying that in the fluids domain, how much force will be required to squeeze a film to like thickness of say twenty micron or thirty micron or fifty micron or hundred micron.

So, like we go lower in the thickness or force will start more and more. So, this is kind of like obvious, but we what is not obvious is like know how these force scales, how much force more value to add now, what is the quantitative aspect of this, that is a very different domain of fluid dynamics working.

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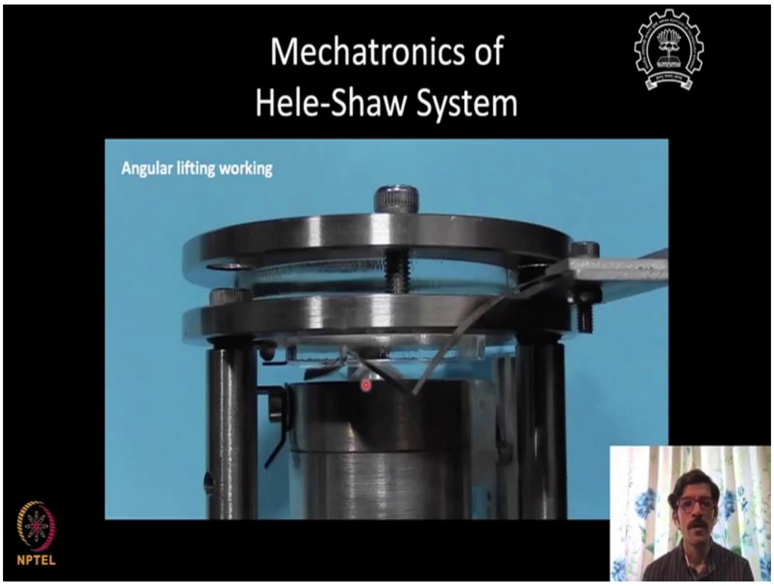

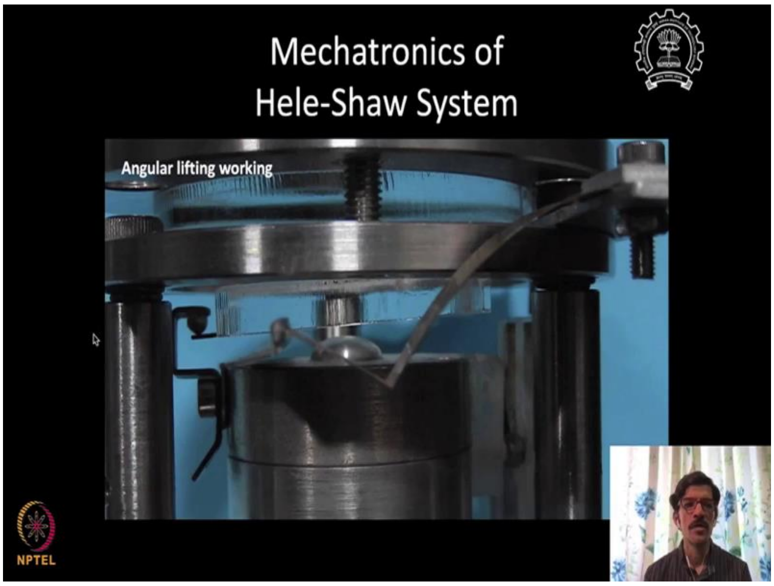

So, here you can see, now this video for Angular lifting. So, you can see before playing video, I will show you this is a point where the force is applied. So, when you squeeze like the plate is squeezed here and then there is no contact between this small gap is maintained there and as you start separating, this gap will be absorbed first and then this plate. So, you can see this is an acrylic plate up here, this is our mechanism which is having a fixed point here and that fix point there this kind of a mechanism design is such that it creates a hinge point at the end of this plate here.

So, you can see that kind of lifting happening. So, part of the lifting you may not be able to see the complete plate, because only the lower part of this plate is getting seen here. There will be some part which is hidden behind this ring. So, let us observe that. You can see as a squeezing starts like this gap will be as a separation starts this gap will be absorbed and then now this is lifting. So, this has lifted completely here. So, this we do not want much angle to left here. We want just a small angle, so that they say this fluid film gets separated.

So, two, three mm kind of a motion is sufficient here. So, this is how this setup is now working.

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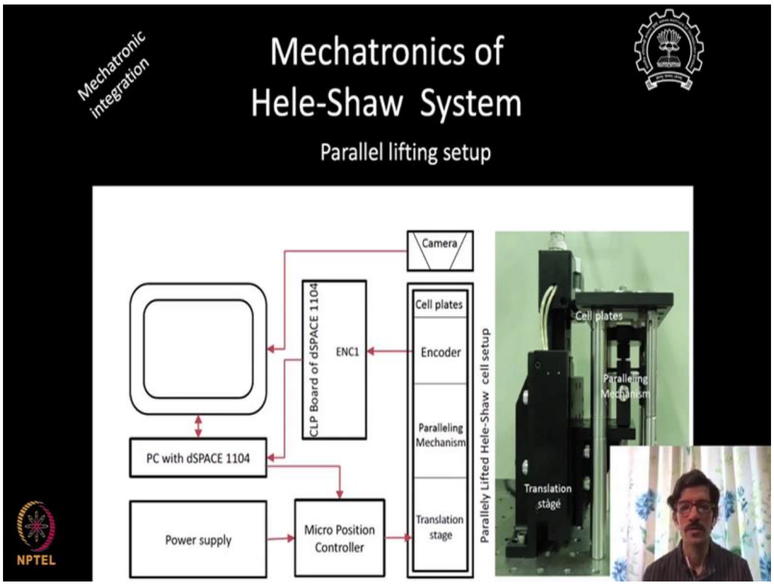

Then what we can do about that we will see in a minute. So, this is another kind of a mechatronic system which is a parallel lifting kind of system. We will not get into too much detail about that only thing here now the actuator is different, instead of the voice coil actuator, now, we are using a translation stage. So, here we are using the stepper motor based translation stage from the Hallmark thing that we discussed in the class at depth. So, this stage is giving us a possibility.

So, this motor is a stepper motor which is having a torque which is much higher than the friction that is there in the system. So, we have seen that for with the micro stepping kind of a driver that is used for the stepper motor, we are able to kind of like move this plate parallel to the other plate in a very smooth fashion here, which is acceptable for our experiments. That is what I would like I can say.

It will still have a stepping kind of effect very small steps. And there will be some micron or sub micron kind of a steps will be there. But that is not really bothersome for our experimental observations to really get to, so that is why I said like we can have actuator both as that voice coil actuator control as a possibility or we can use these stepper motor kind of actuators also. So, here there are these ball bearings two kind of add this in the vertical direction down and stepper motor to actuate.

So, a lot of friction is existing in the system, but that is getting overcome by the stepping separate torque and even then we are able to move in a small steps at a very slow speed. So, this action will happen now as a small steps. So, this is not really kind of a continuous smooth kind of emotion, but it is going to be in the steppy kind of a fashion. But did not see these steps are very very low in size, we do not have any problem in really executing this setup.

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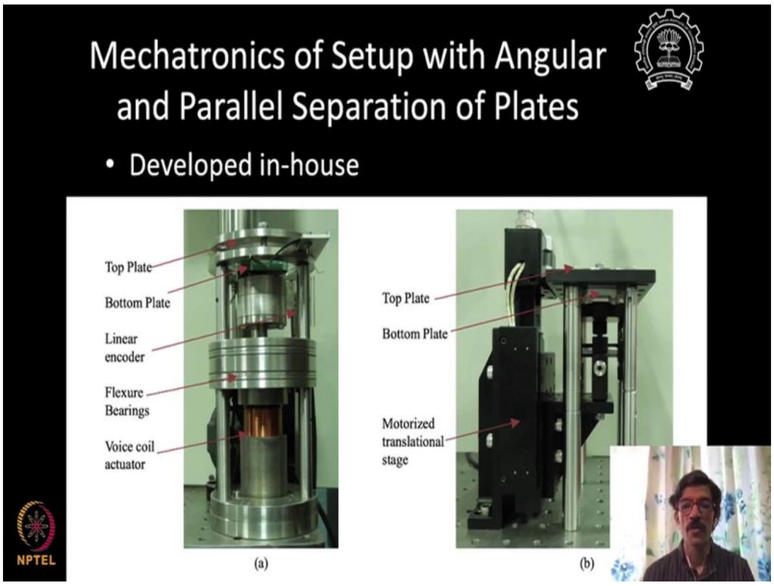

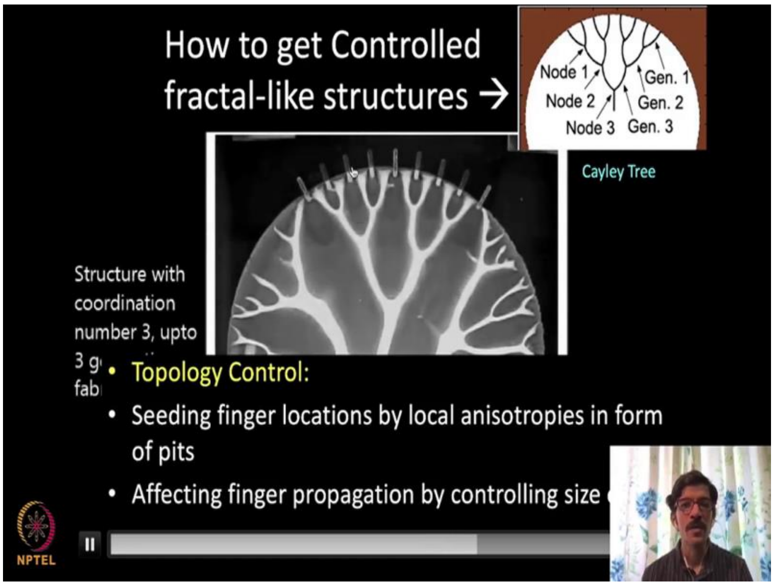

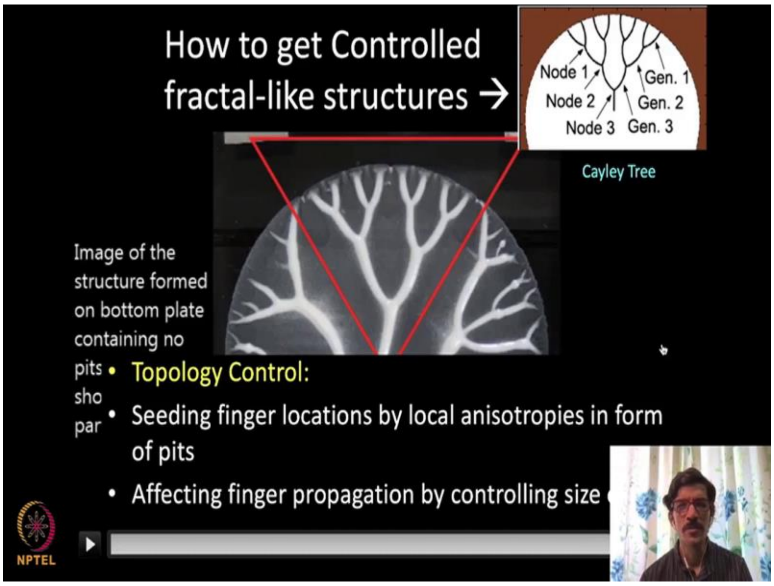

Now, what we have done with these setups. So, both are both of these items are like put developed in house for as a mechatronics system. And what we can do with these setups is what I will talk about a little bit now, to give you some kind of a sense of what interesting the ideas are or you know fabrication these setups can do. So, this is where like we introduced this you see this video here the this is now top camera recording this thing where the squeezing happened just now, the squeezing of the film has happened here already.

And the there are this small little trenches that we have machine on the surface of this plate, one of the plates. And then you can see that now the fluid, the air starts penetrating through those trenches preferentially. With this air penetrating that the through them that designed to kind of do some kind of dimensions. So, that I can know there is this air it does not progress too large in this plane, but in this kind of air finger progress is much larger distance and these places much larger distance these places even larger distance and that.

Like that we have designed these trenches to be. So, with this we are able to now produce like the controlled structures where you have one branch splitting into two branches only and then further splitting into two branches only, further splitting into two branches only. But at the other place where we did not have this a anisotropies on the cell plates, this is a random process is happening still. So, this is how we exercise additional control. So, the control that we had so far was only the speed of the plate for motion.

Now, we have these additional controls that are coming up by virtue of some kind of anisotropy is on the cell plates. So, in the form of these pits or holes or some, so these plates are no more planar plates, these are like having some holes. And now we are using acrylic plates, so that we are able to see through the plate to, see what is happening to my fluid and also we are able to machine these acrylic very easily. I will show you like know how this entire process goes in a minute.

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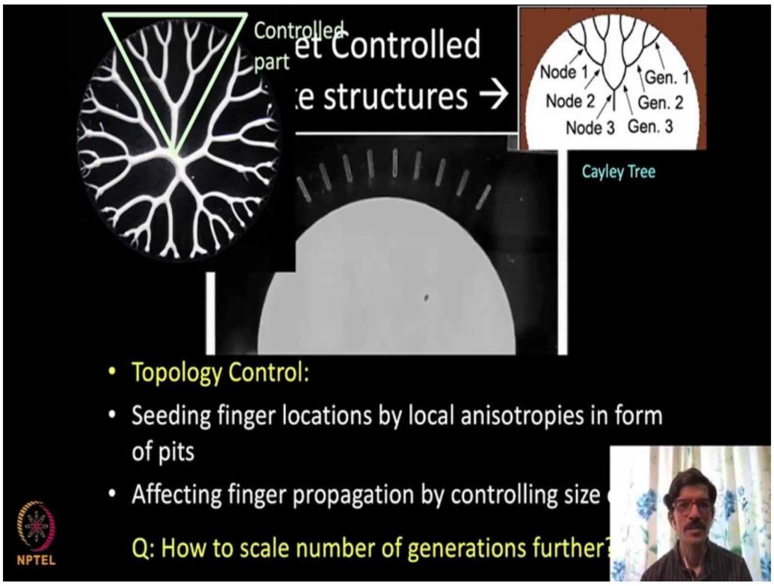

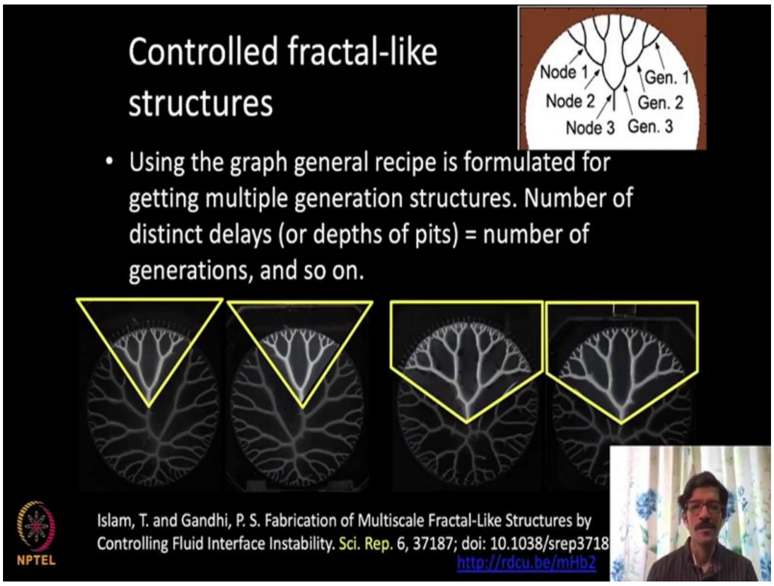

So, now let us see this kind of a topology is coming up on the, so this one can see that this this can be scaled further and do a lot of different things with this. We have this picture which shows that we have this by studying these process phenomena in much more detail in the fluid dynamics kind of a domain which we are not interested right now because we are like looking at for mainly Mechatronics perspective, but we are able to fabricate then like these multiple generations of these splits.

So, this is like first split here, second split here, third split here, fourth split here and fifth split here. So, like five generations we are generating these fractal geometry structures. And this process can be useful for as I said like some biological kind of applications.

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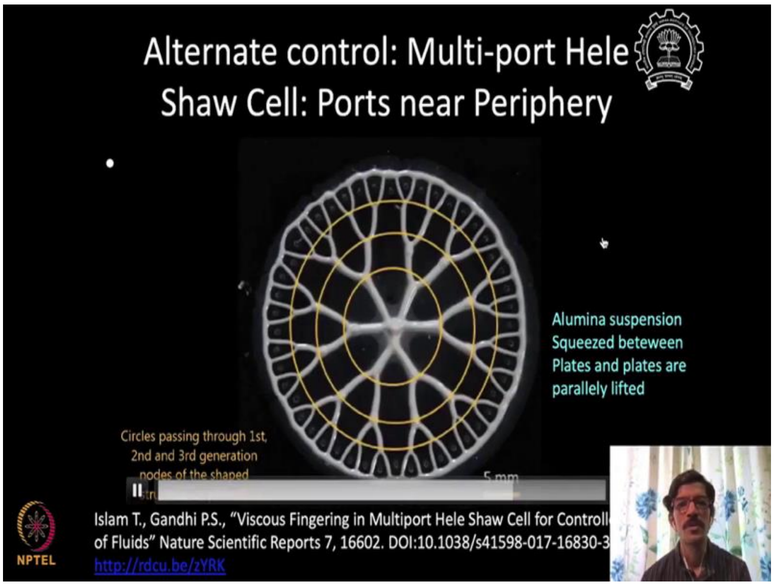

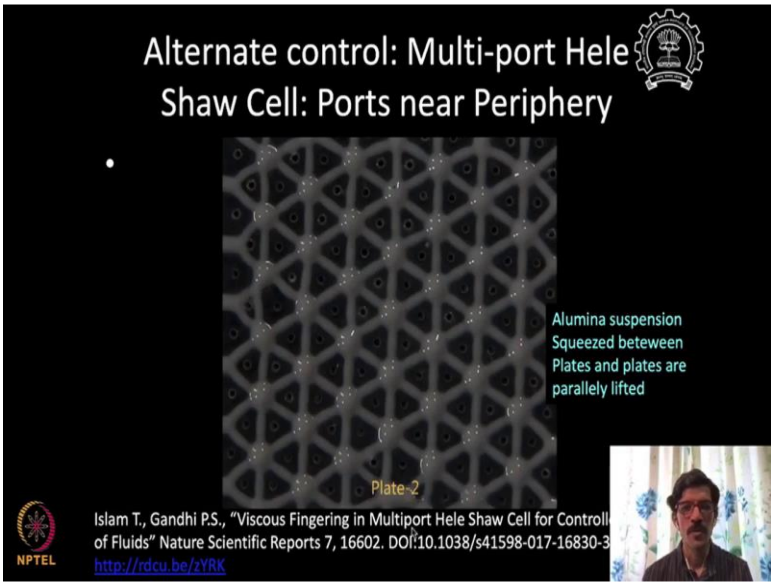

Now this is alternate control, another control that we are exercising by putting them holes now instead of just those kind of scratches or some kind of pits. Now, these are a holes completely through and through holes and they are allowing the fluid the air fingers to grow. So, how do we kind of make them grow more or less like there are a lot of some kind of a study has been done about that and all these kinds of things are arranged in a way that this kind of complete symmetry of the structures can be possible to be produced.

So, again the process is exactly the same like in the mechatronics kind of a perspective, we are still squeezing the fluid and then separating it out, that is it. But now, we are able to produce with that process a very interesting kind of structures and these structures can go with the array kind of a pattern they can go as a full like triangular array of fluid and then further like hexagonal array or some other kind of a possibilities that can be there.

And this can be done now like no on much larger scale as long as we are able to manage that big size scale see big size plate motions, this can be done at a much higher kind of scale. So, the scalability is there inherent because it is just a fluid that is going to be working there in all places.

So, we have worked out some kind of non-dimensional numbers under which these processes will happen very easily and things like that in the fluid domain what are the non dimensional numbers governing them. So, if you have in case you are using your own fluid, what is what are the properties to look for and things like that. All those details can be found in this paper.

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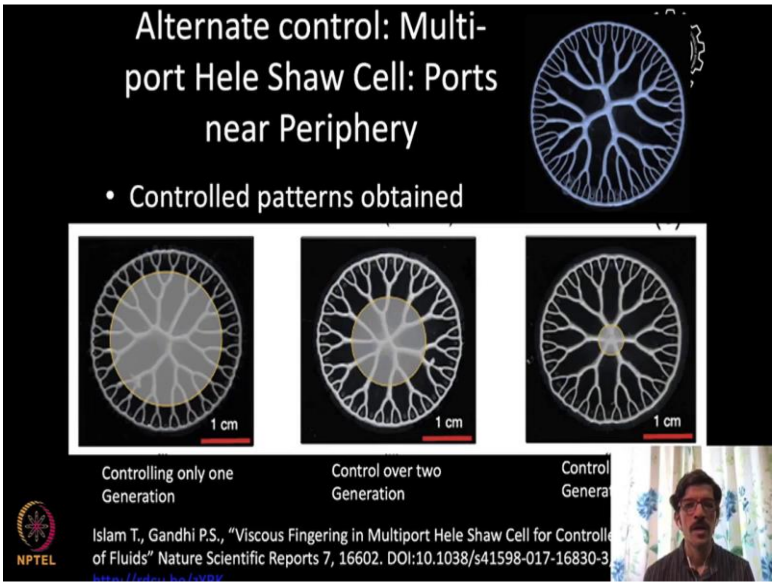

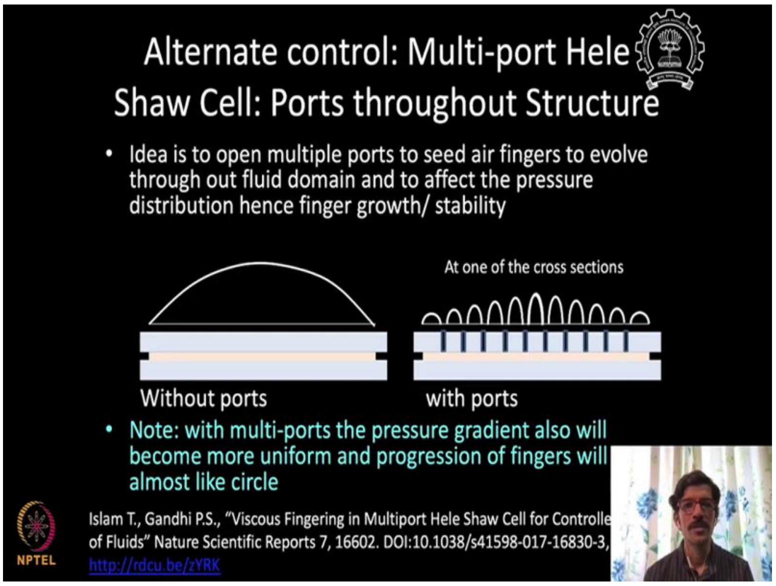

And then these are like multiple kind of versions of such structures, different patterns. And then you have these with the multiple holes now, instead of just holes on the periphery we are using now holes everywhere and then what are the pressure curves that this is a cross section of the or the this is like a showing the pressure that is built up in the inside this film like a parabolic kind of a fashion, but when we have this multiple holes then like the pressure built up does not happen so much. And many places you will have this, wherever these holes are you have atmospheric pressure there, which is like horizontal line here.

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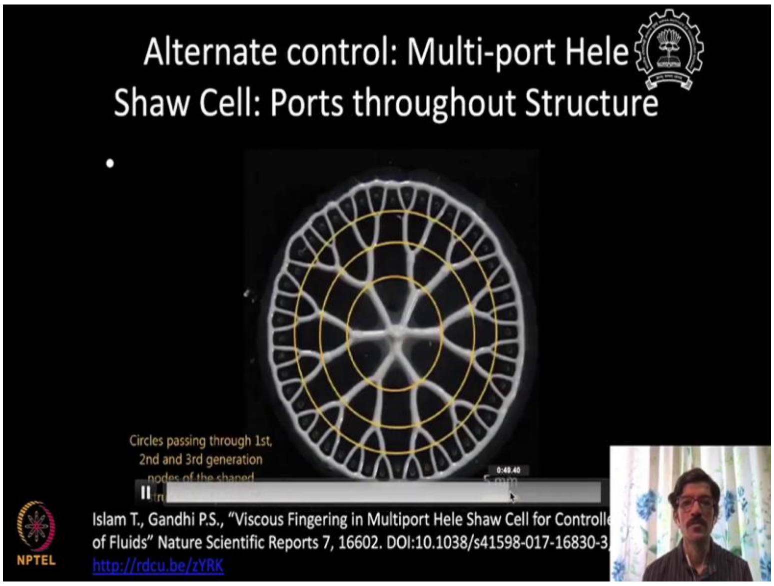

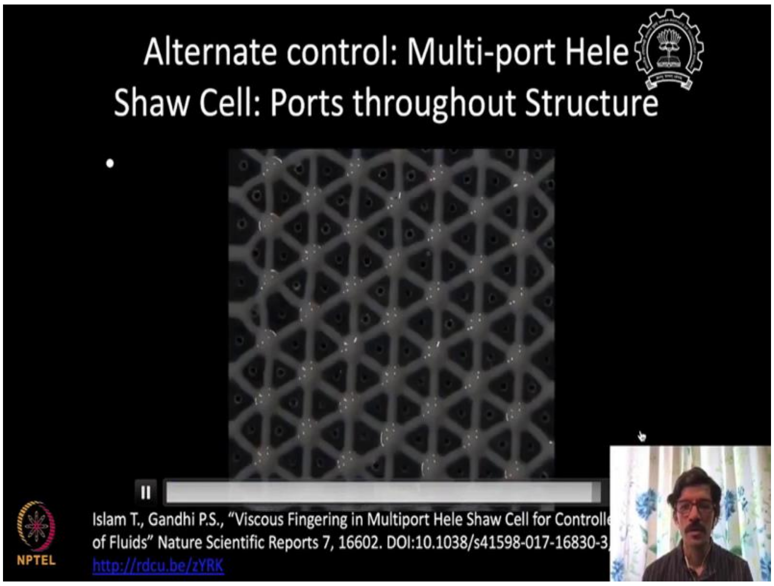

So, this pressure gradients as we saw already in the previous video, this is also working now, for giving you these, different kinds of patterns. You can see here this triangular shape patterns and we will show some other patterns also.

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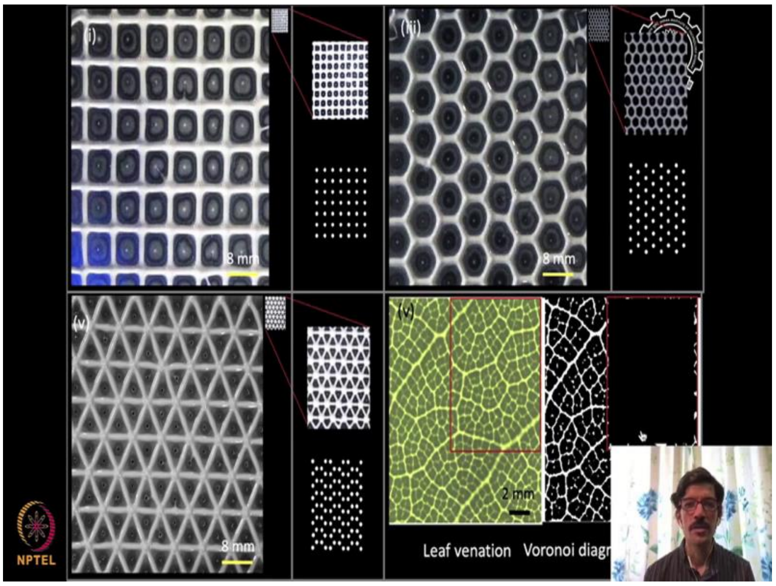

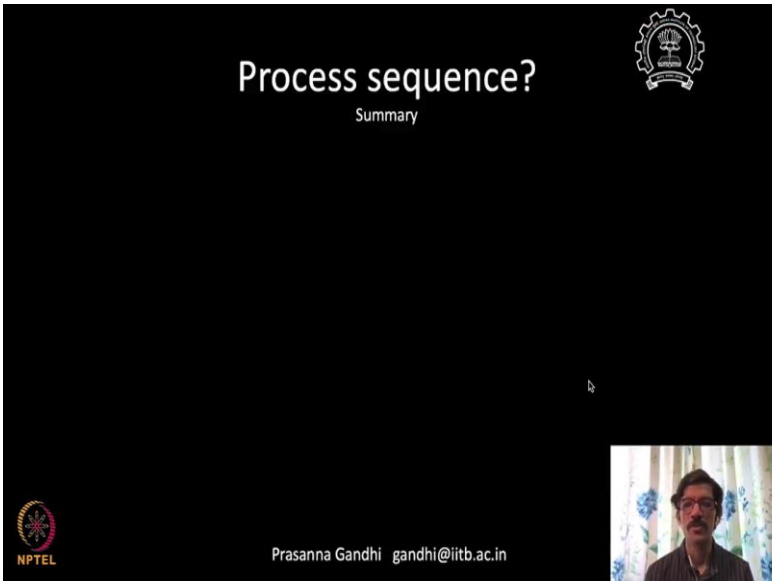

So, let us see, these are the other patterns that can be produced, you can get square patterns, you can get hexagonal patterns and you can leave, mimic the leaf completely in that if vein speed took this image and by processing image we found out what are the anisotropies that had to be there on our cell plates and we can produce that also reproduce that also. So, here is the thing, this image is missing here, but that image was showing actually the reproduction part of these veins.

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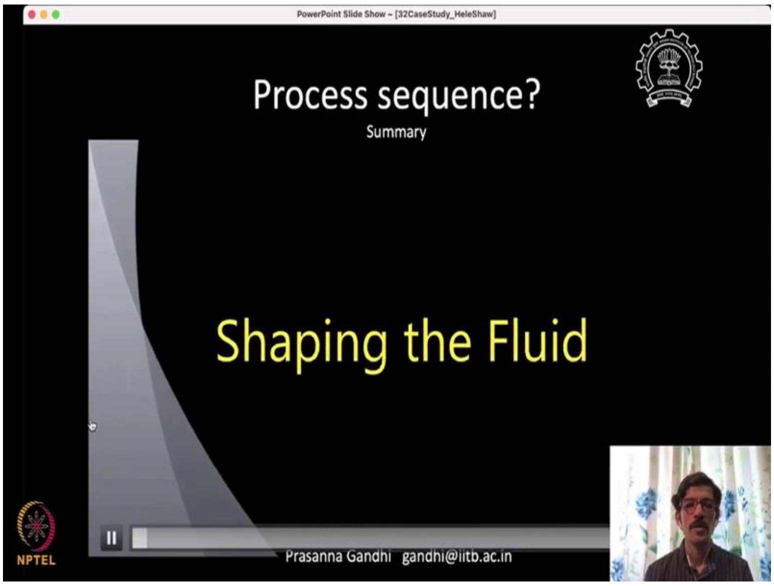

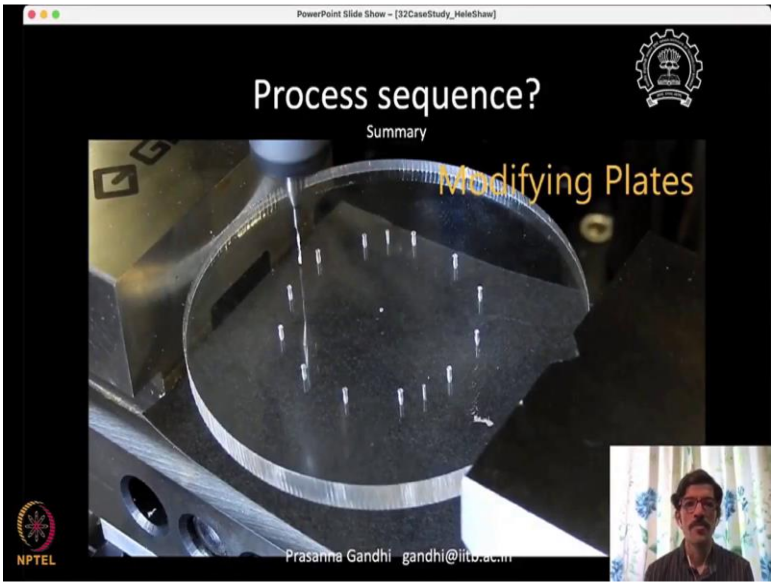

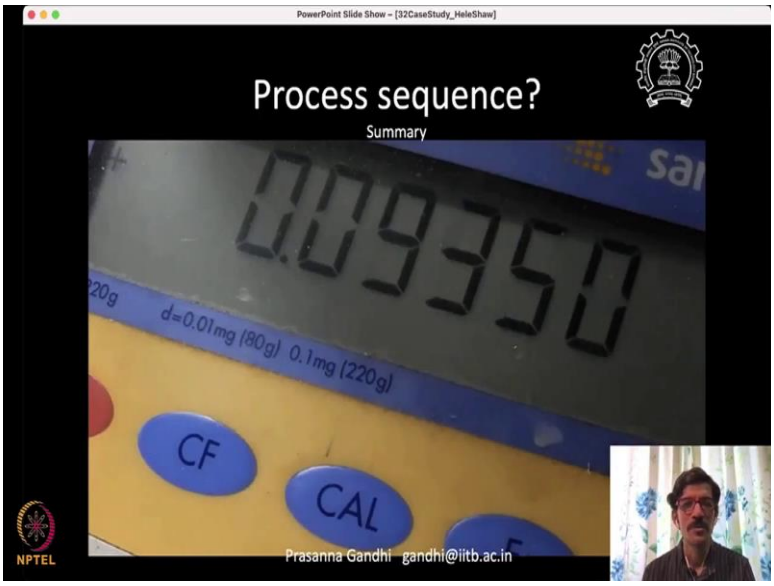
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Summary
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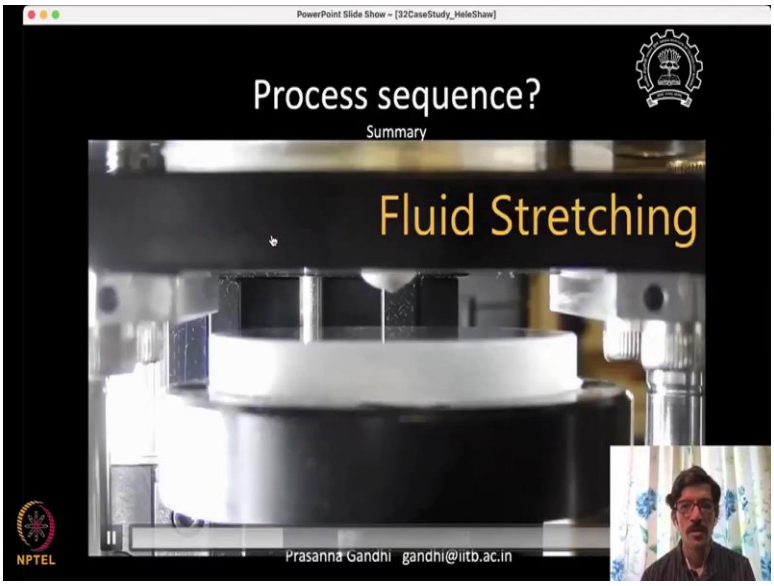
d=0.01mg (80g) 0.1mg (220g)
CF
CAL
Prasanna Gandhi gandhi@iitb.ac.in
NPTEL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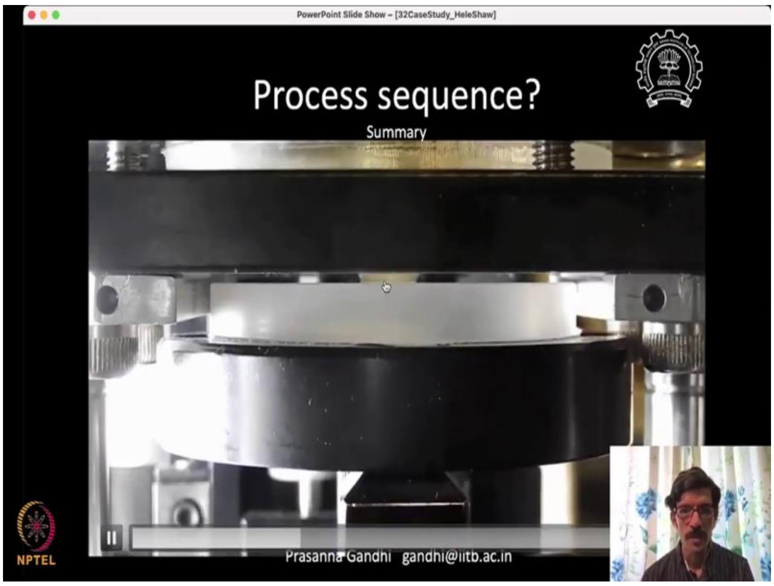
Process sequence?
Summary
Fluid Stretching
Prasanna Gandhi gandhi@iitb.ac.in
NPTEL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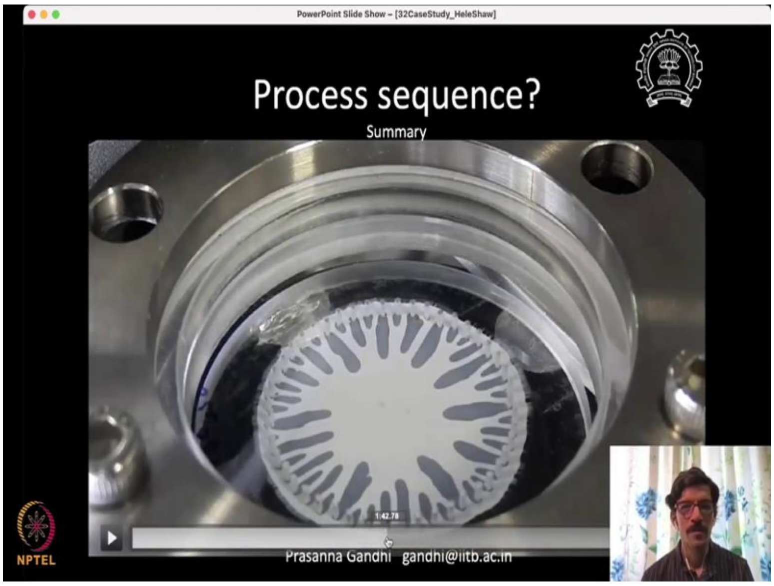
Process sequence?
Summary
Prasanna Gandhi gandhi@iitb.ac.in
NPTEL



So, then the total summary of this process is somewhat captured here. We can see this video now. So, this starts with this one setup here that we just saw in the previous slides also and the process starts with is modifying the cell plates. So, you can see this is the cell plate here and it is like the we have this home developed a micro drilling kind of a system here. So, we have used these motors for this from the aero modeling, the propeller motors and one can have very high speed for those motors and we can design this kind of a, now again Mechatronics system of drilling holes, micro holes which is done in house.

So, now we have put a fluid droplet here which you see this upside down droplet up here. And we will start squeezing the droplet by giving now the rotation to the ball screw. And in this fluid film is now droplet has touched and fluid film is getting squeezed. This fluid film gets stretched and it touches this whole size we saw.

And then we will do it at high speed will not get the geometry that we want. So, we do it as a slow speeds or the speed that we have calculated a priori and then this geometry starts coming up in the thing.

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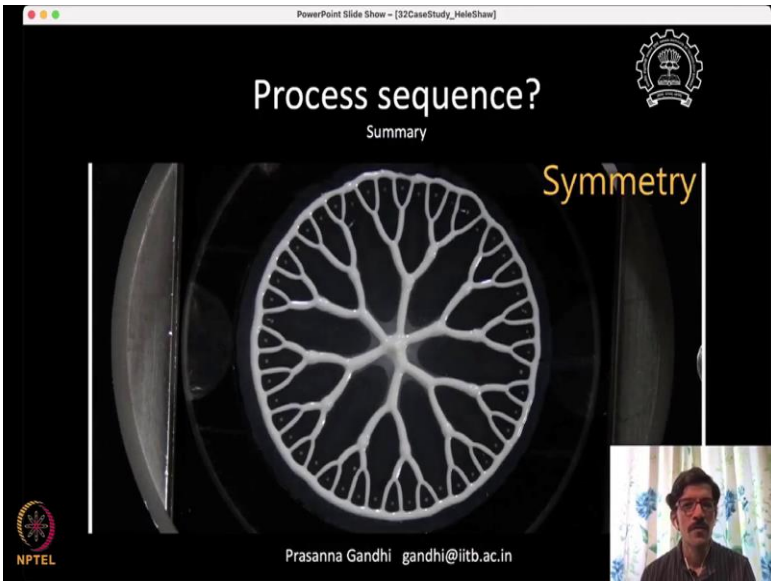

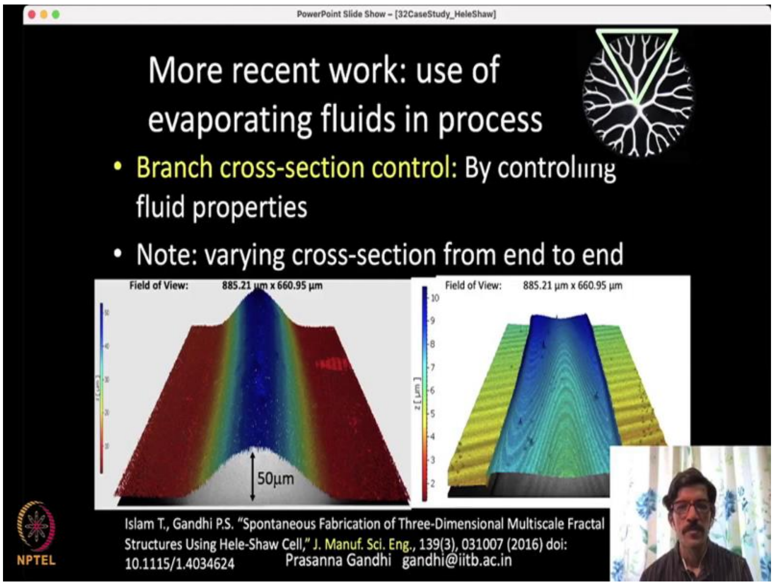

So, this is how you see that. Now, you can see many different kinds of geometries that are fabricated by this control and this is a different setup. We can see these flexure bearing up here. So, maybe we can go back a little bit and then see this spiral fracture bearing up here. So, let me pause here. You can see that these are spiral grooves here for the bearing.

The spiral grooves in the plate can allow this up and down motion happening and such kind of a bearing is there at one end and the other end and these two ends will constrain it to move in a straight line up and down. So, this is how the angular lifting set up that mechatronic we have seen. And then this is a experiment with that.

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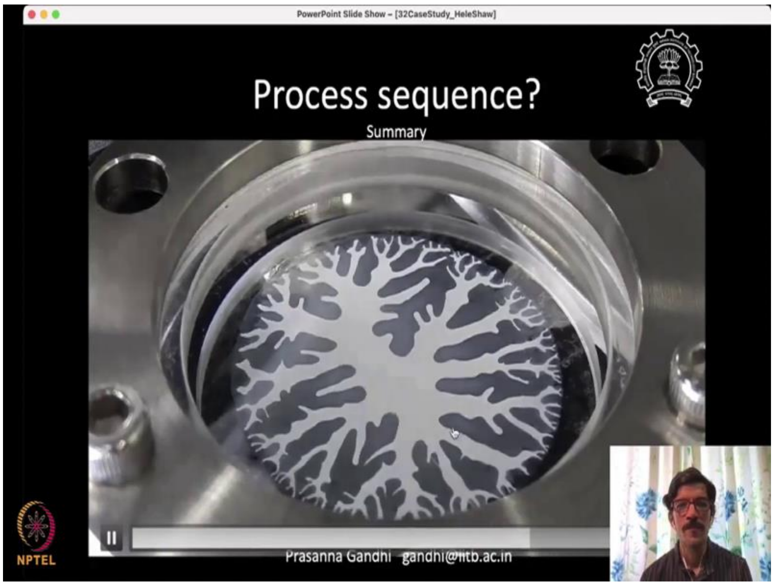

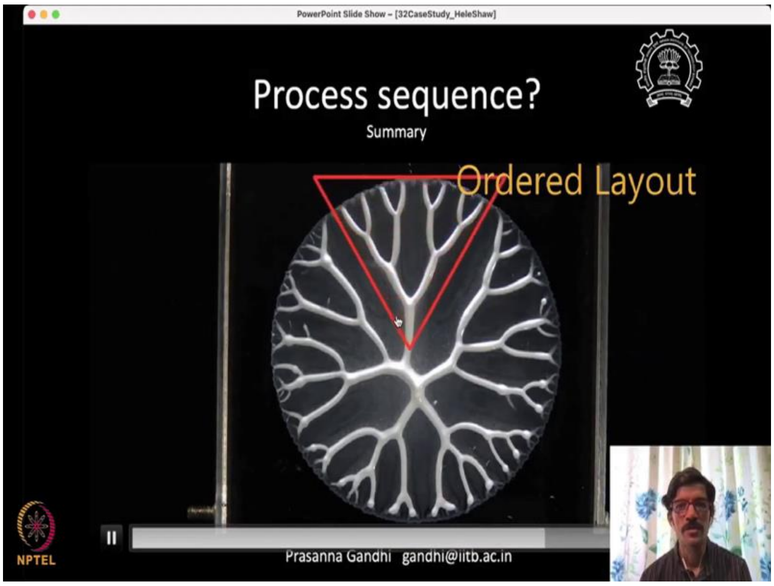
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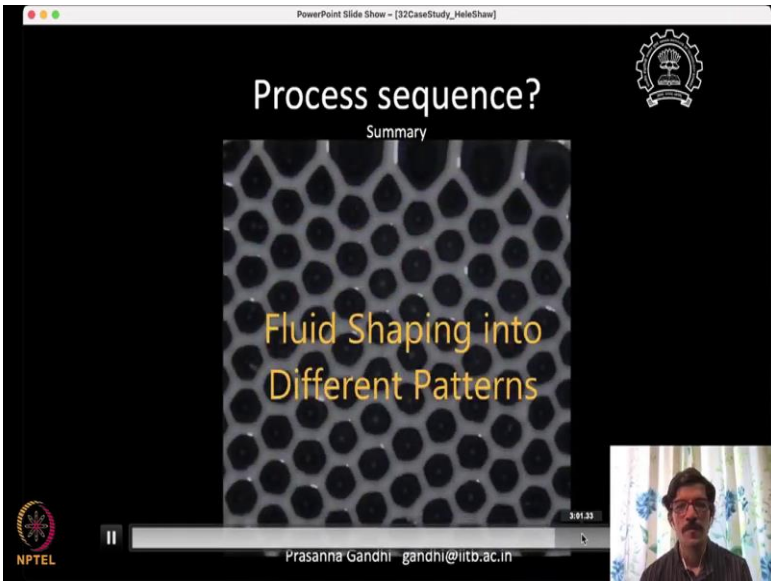
Process sequence?
Summary
Ordered Layout
NPTEL
Prasanna Gandhi gandhi@iitb.ac.in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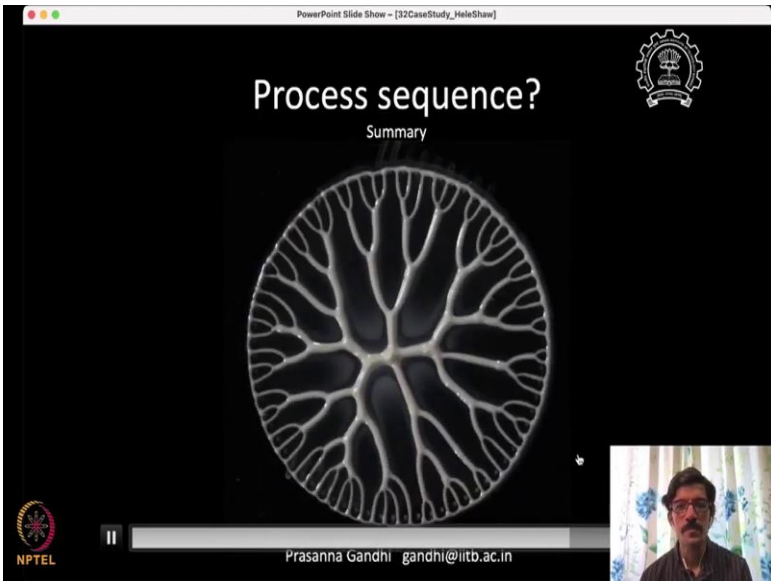
Process sequence?
Summary
Fluid Shaping into
Different Patterns
NPTEL
Prasanna Gandhi gandhi@iitb.ac.in


PowerPoint Slide Show – [32CaseStudy_HeleShaw]
Process sequence?
Summary
NPTEL
Prasanna Gandhi gandhi@iitb.ac.in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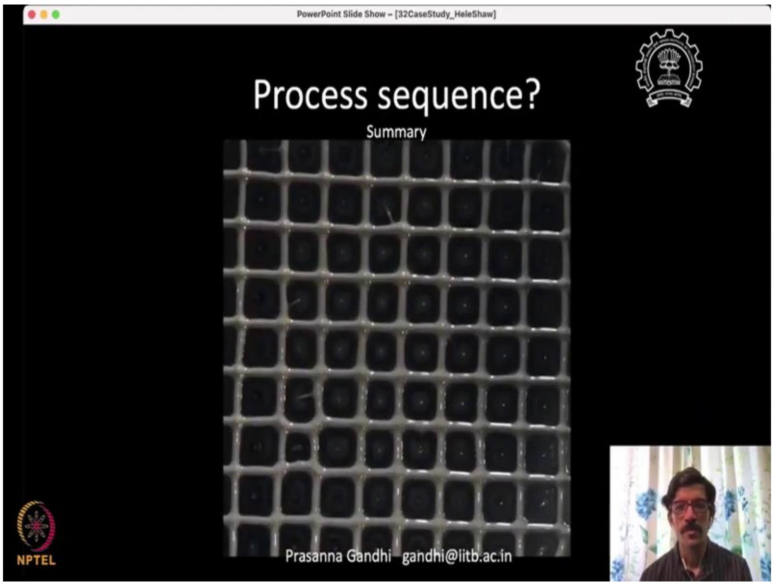
Process sequence?
Summary
NPTEL
Prasanna Gandhi gandhi@iitb.ac.in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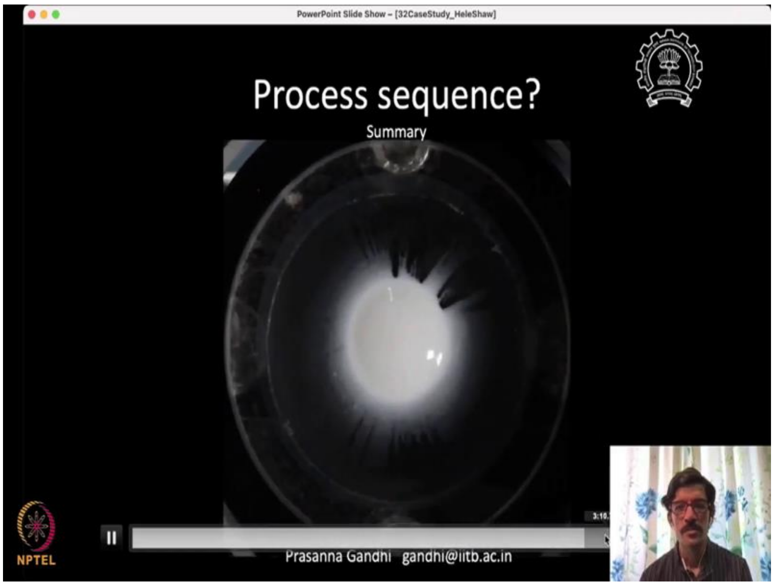
Process sequence?
Summary
NPTEL
Prasanna Gandhi gandhi@iitb.ac.in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Process sequence?
Summary
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Prasanna Gandhi gandhi@iitb.ac.in


PowerPoint Slide Show – [32CaseStudy_HeleShaw]
Process sequence?
Summary
Prasanna Gandhi gandhi@iitb.ac.in
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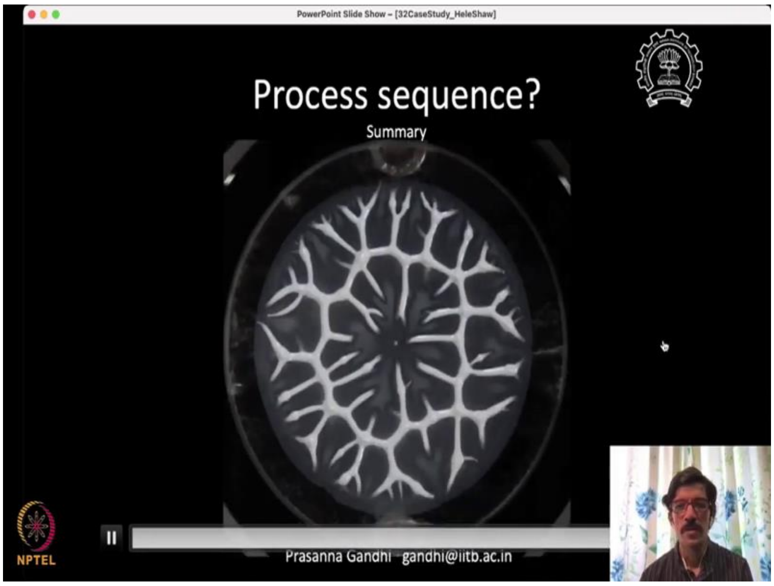
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Process sequence?
Summary
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PowerPoint Slide Show – [32CaseStudy_HeleShaw]
Process sequence?
Summary
Prasanna Gandhi gandhi@iitb.ac.in
NPTEL

So, maybe we just, I think we have seen so, this is see if you do not have any anisotropy or you do not have any control, this is how the very slow the process is moving very very slow at whatever five micron, ten micron per second speed you see these fingers evolving in real time right now actually.

And then they evolve and like then they form some patterns on the surface. This is without control and then we have with control we have this ordered kind of a structures here. And then different patterns coming up here. So, this is what we have seen already some part. So, maybe I think we can skip the rest of the part here are these different different interesting patterns that can be fabricated.

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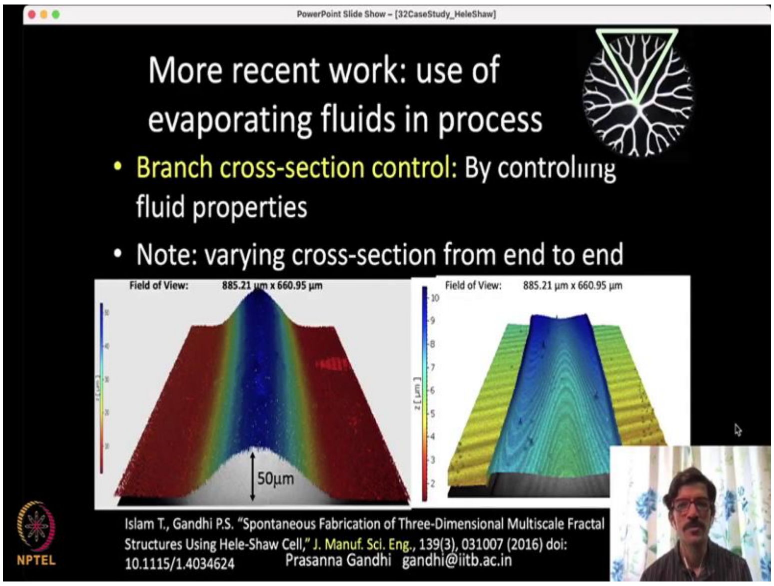

And one can explore this more I mean, when different different kinds of fluids you can have different possibilities. Say for example, if you use evaporating kind of liquid, evaporating solvent is evaporating, then you get these kind of patterns. So, this is a combination of liquid drying on the surface and this Hele-Shaw process.

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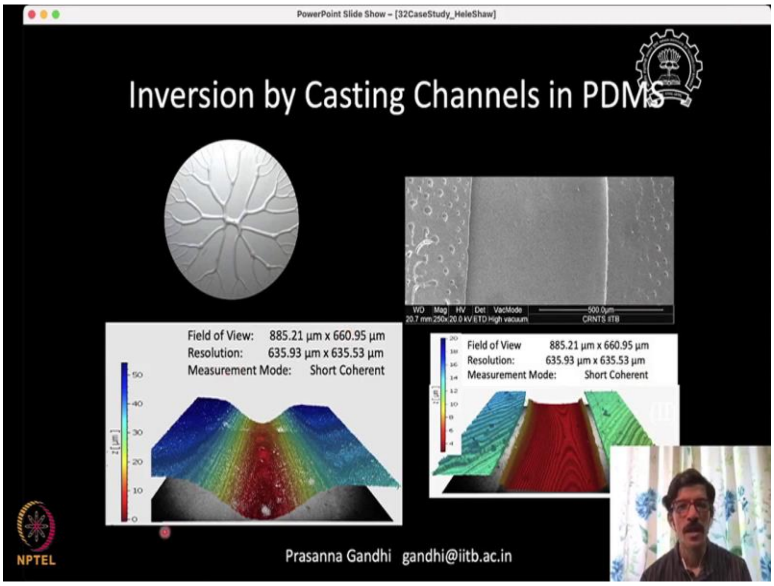

So, this these kind of patterns are very easy to get in this process and then we can invert is by casting in the material called PDMS is a kind of rubber kind of material in which these can be casted and then this can act as a micro channels. So, these things will have act as a micro channels of different cross sections.

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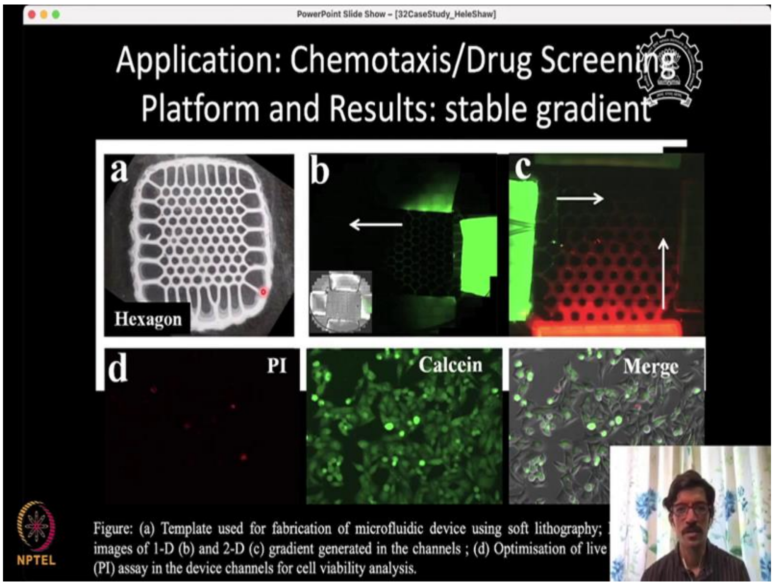

So, we have one of the applications with one of the collaborators Professor Abhijeet Majumdar from Chemical Engineering in IIT Bombay. We are developing a platform for drug screening or chemotaxis. So, we will not get into the details of this application, but the point is to say that this is kind of a research will lead to some kind of applications eventually.

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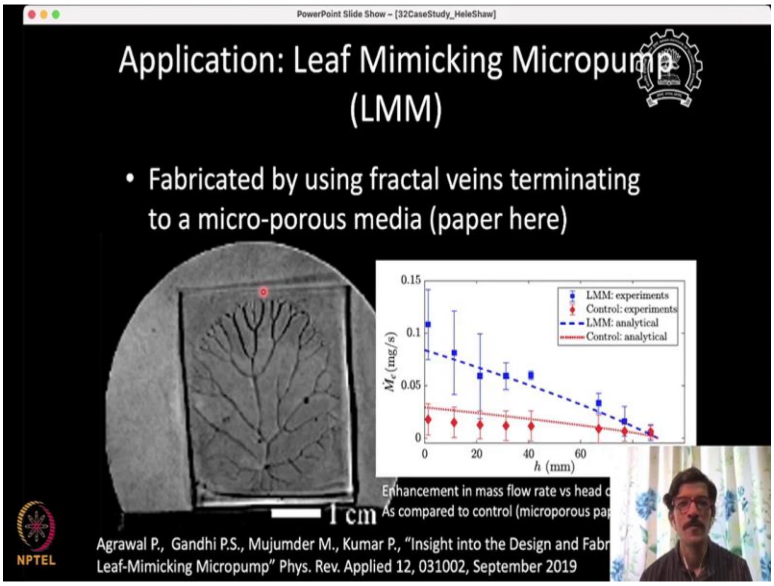

This another application where we have a leaf mimicking micro pump, that has been developed here.

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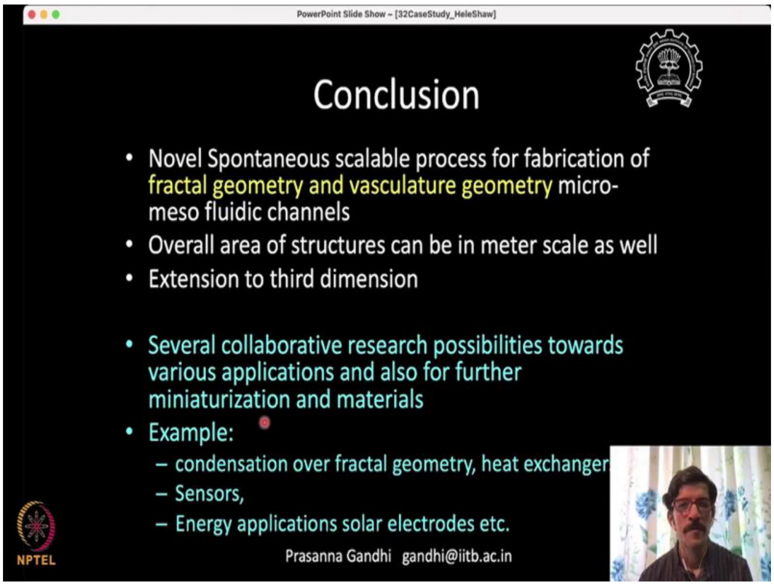

So, there are many many different application possibilities and collaborative possibilities for such a kind of work and we can explore those in the future in more detail. So, say for example, there are this condensation over the spectral geometry or heat exchangers with this kind of geometry.

There are some of the kind of sensors with these or energy application solar electrodes or the or even the electrodes for water splitting to get hydrogen generation or hydrogen production done. Like those lot of different kinds of possibilities that exist and some of them we are exploring in our lab and you feel free to explore what you want to buy. And then feel free to talk to us if at all you want to like have some application to be done.

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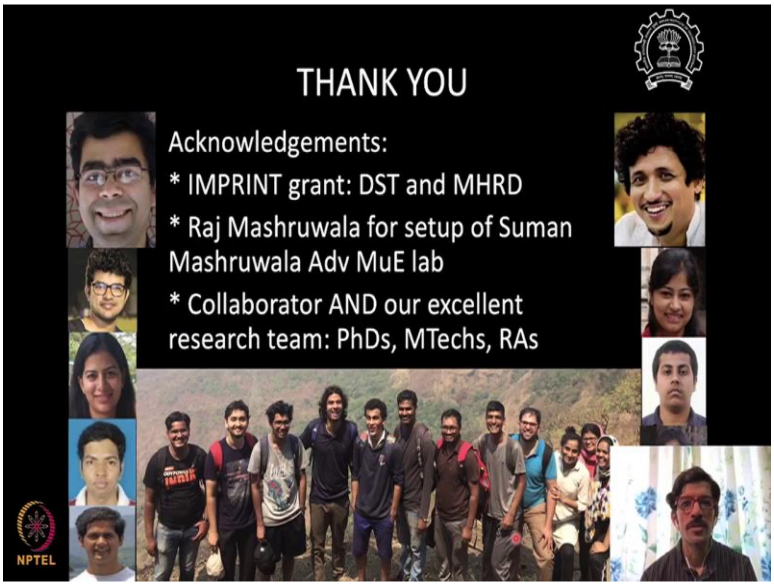

So, this is, like know, the team that has worked behind this and must acknowledge like IMPRINT grant, which was which funded this project and is, they are my collaborators, faculty for this particular part. Professor Amitabh Bhattacharya, we are collaborating for the theoretical kind of aspect and Professor Abhijeet Majumdar from Chemical Engineering for a bio applications in this domain. And either of course is a big team of the students and research RA's and PhD's students who are working behind, although I am getting an opportunity to present this work to you.

And then there are industry collaborators, like Dr. Dhananjaya and Menon from strategic automation and Dhananjaya from Achira labs. So some bio applications future development we are doing with them. So, thank you very much. And I am hoping this course will give you a good lead in developing your own kind of mechatronic systems in whatever application areas that you are helping. Thank you very much. Bye, bye.