Design of Mechatronic Systems
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Lecture 46
Case Study: Development of 3D Micro printing System

So, far in the course, we have looked at many different concepts which are helpful to design mechatronic systems, various kinds of mechatronic systems. Now, we will see some kind of a case studies to see how whatever we have learned can be put together to build some innovative kind of systems. So, we will go through some of the research examples from our lab and we will talk about more details, how these systems can be really built by using some of the concepts that we have learned. So, let us start with this.

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So, this is a lab called Suman Mashruwala advanced micro engineering lab that we have developed in department of mechanical engineering, IIT Bombay and this lab, I must acknowledge the funding by our alumnus, Raj Mashruwala at that time about 2007, we developed this lab with the funding of about a million dollars from this alumnus. And beyond that a lot of activities have happened in the lab and a lot of new projects have come and the facilities got extended anything here. So, here is we started out for activities.

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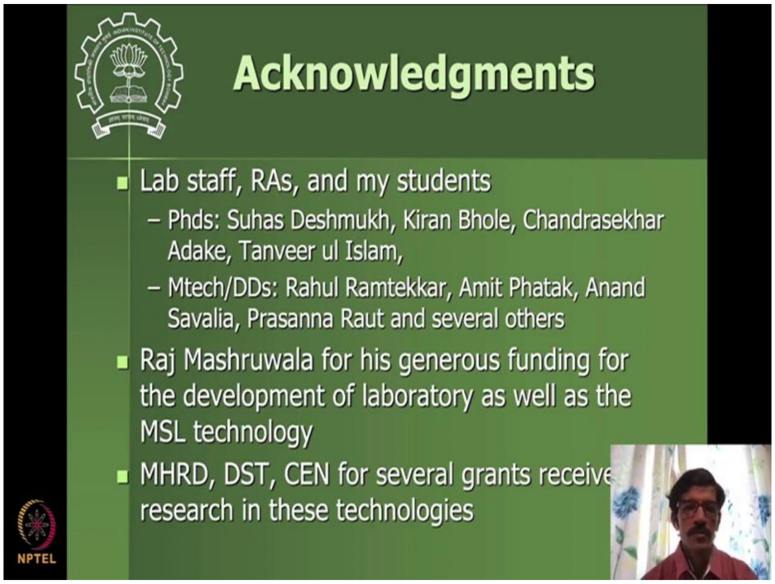

So, before I begin, like I will acknowledge this all the researchers or ours PhD students and MTech students and RA's who have contributed to this work and of course, the funding I mentioned about and there are many other grands that we received later for the research that we are going to see about.

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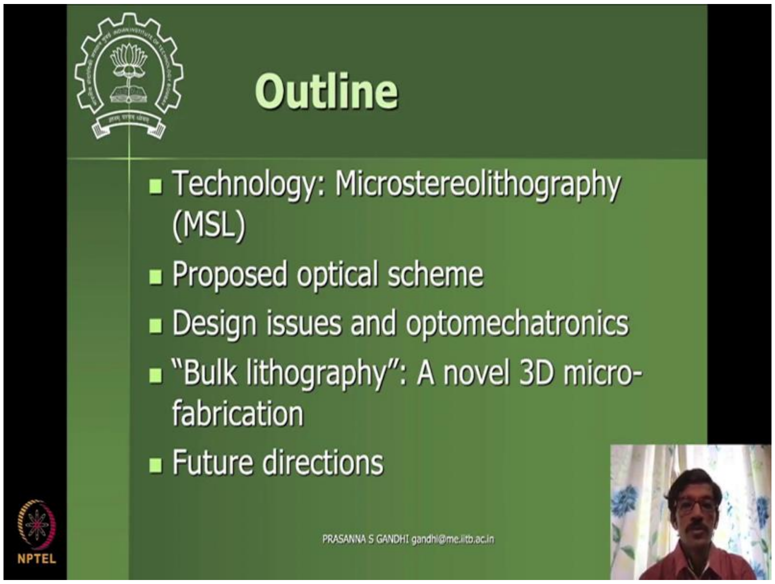

So, this is like roughly some outline of the talk right now we will you use this for 3D macro printing purposes, technology of technological micro stereolithography. I will talk about is similar or 3D printing in SLA kind of technology, but I will talk about that and then we will see what are the novelties that we have come up with and how like know some of these mechatronics concept we have integrated into the systems to make sure they work the way we would like to have them work.

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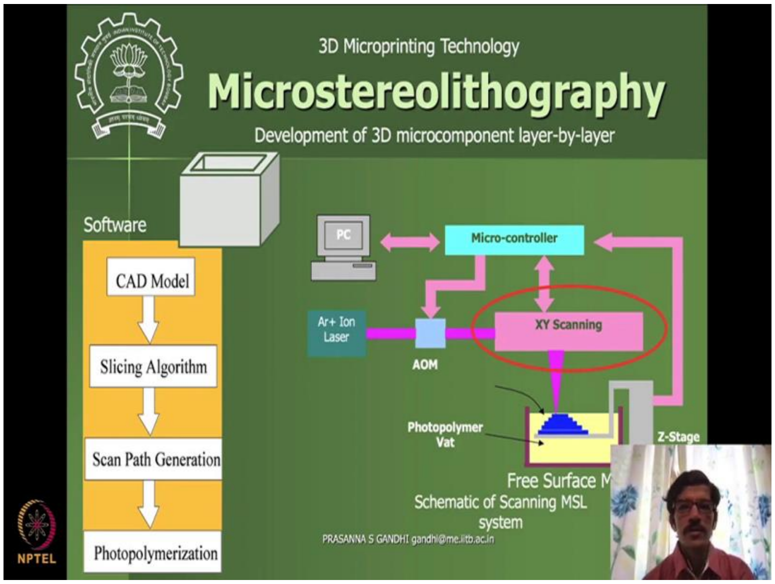

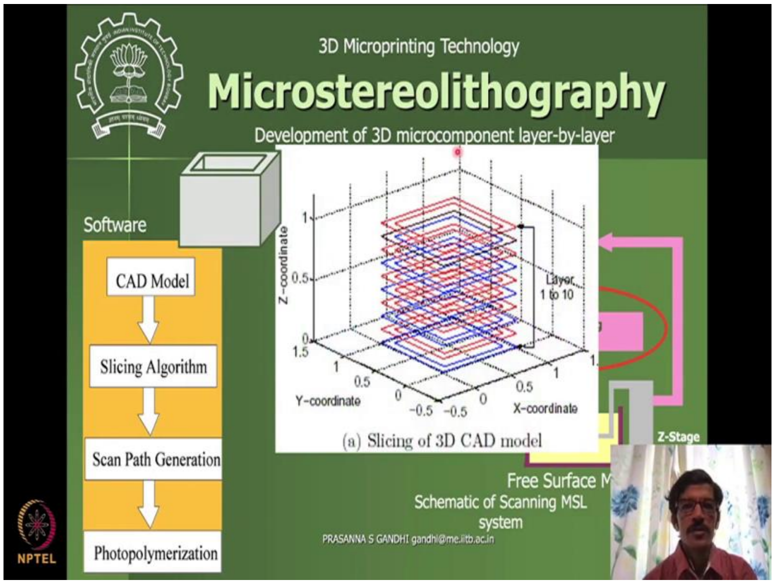

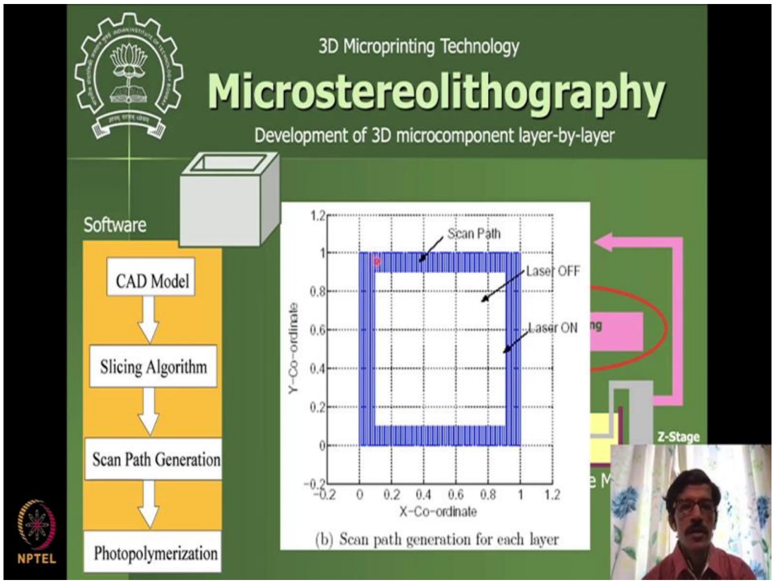

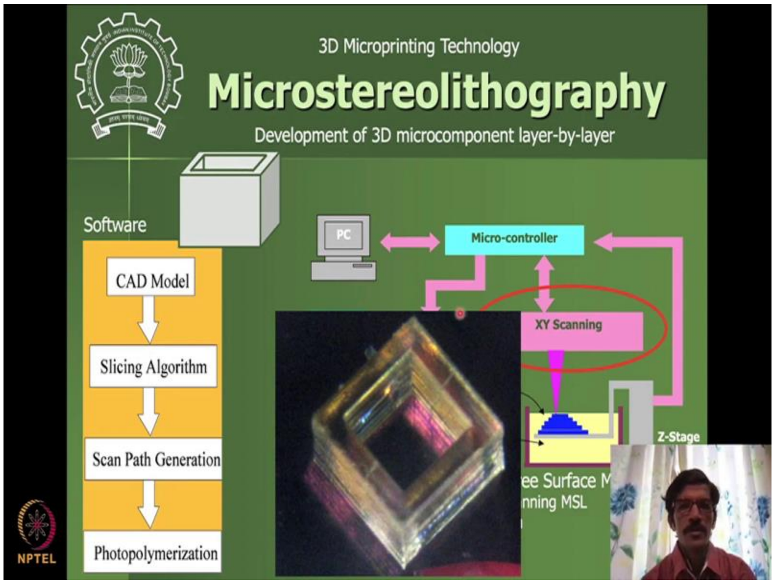

So, this micro stereolithographic is a simple technology of 3D printing, we start with the CAD model in the software and this CAD model as you see here is then software sliced into different slices. So, these are the software that we have developed in house to create the slices from this CAD model and then further the slices are divided into lines for the scanning.

So, each of the slides will be scanned by this line and now if you are if the idea is the to run the laser along this line, so that photopolymer resin will get cured only at this part where that there is scanned and laser needs to be getting switched on and off at these data points. So, this is how the requirement for the 3D printing in SLA kind of a way is similar to other kind of technologies that also exist for 3D printing. So, the when you scan you get this kind of final product out of the system.

Now, the question is like, when you want to do it at a microns kind of scale the scanning becomes very important and the scanning system needs to have much better accuracy at a sub-micron kind of a scale. So, this accuracy can be provided now that we have gone through this course, we know that for a very high precision motion, the compliant mechanism stages are going to be useful. We have seen that in the CD ROM kind of example. So, we developed this concept for the compliant mechanisms later for this scanning purpose. But to scan the laser beam, there can be different kind of methods for scanning.

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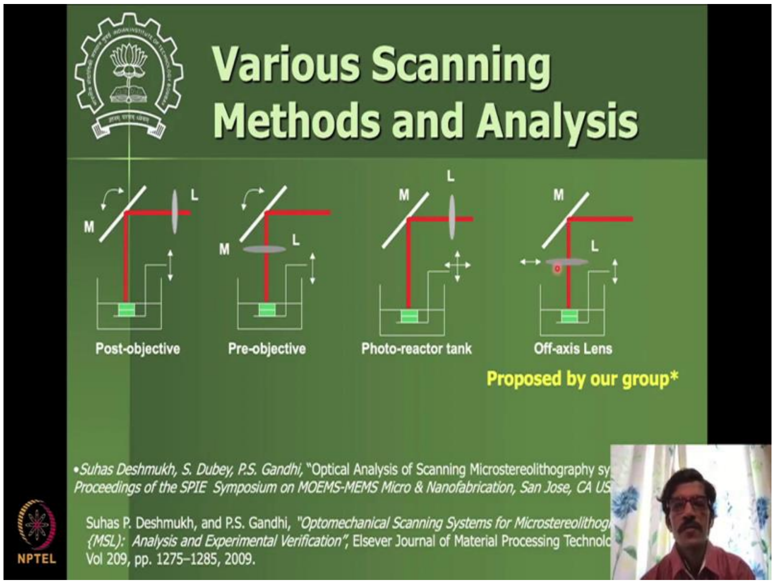

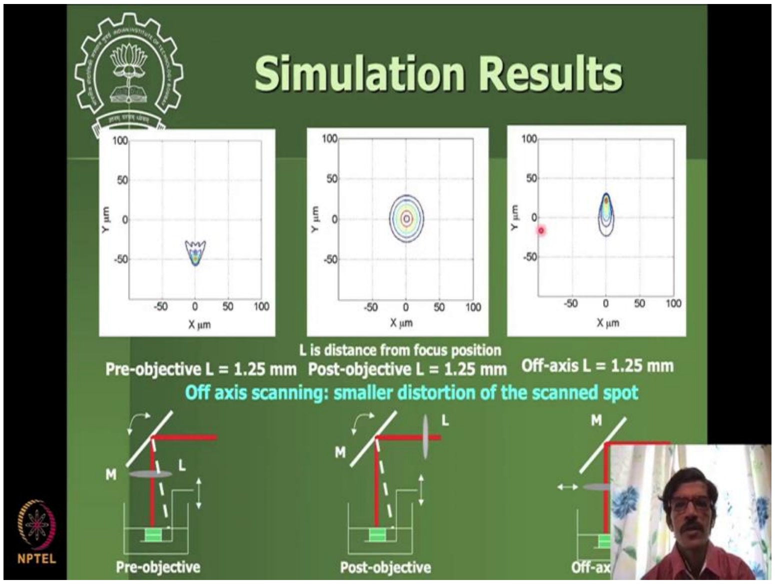

So, some of these methods are kind of demonstrated here. So, you can have these mirrors which are kind of tilting and then the lens is focusing the laser beam and then as mirror tilts the laser beam is going to scan on the surface. Then you can have the laser beam scan and then the lens is placement is now different than this kind of a method and then in this case your tank itself is moving the laser beam is stationary.

So, each of these systems have some advantages, disadvantages one can see. For example, this system if you see the scanning goes over the sphere and you are actually the surface on which the photo polymerization happens is flat and this is what happens is like the then laser gets defocused at other places and when you want to create a micro scale kind of component you need a laser focal length to be very very small. So, that the focal spot is small in size and for such a small kind of a focal spot and then this becomes very difficult or infeasible to move this mirror and still keep some reasonable kind of resolution of the component here.

Because as the laser gets defocus the resolution gets compromised. So, we propose like a new way of scanning laser beams we actually propose two ways one of these is these but these is also better than all the other methods but it is a great kind of a method of scanning the laser lens here itself in the linear kind of a fashion, laser is fixed but the lens is scanned in the linear fashion. This we proposed first and then like we say that it has some kind of benefit but it is not great.

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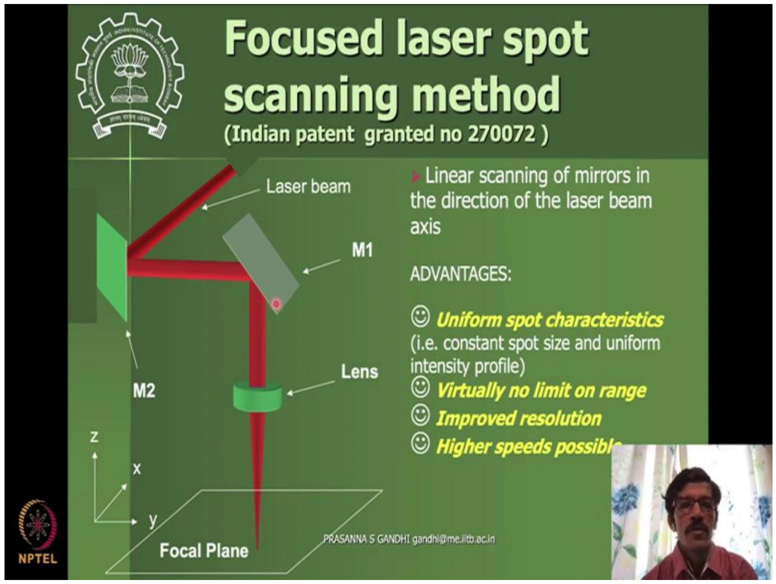

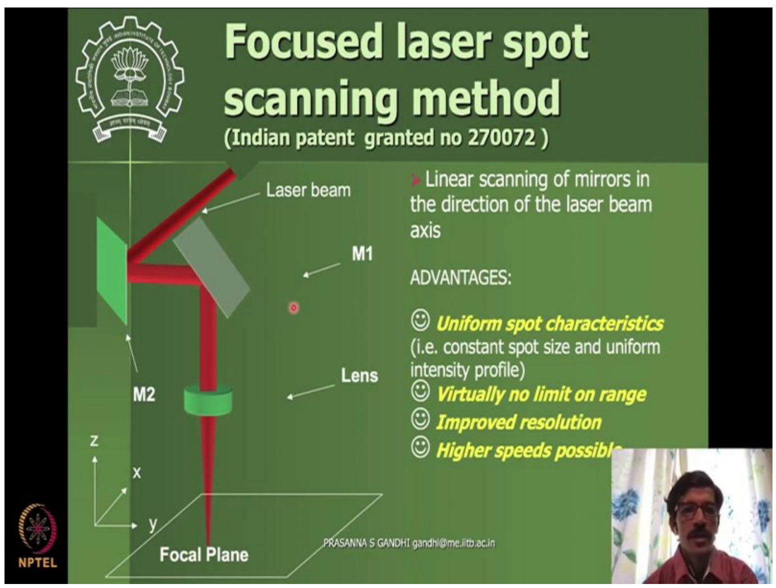

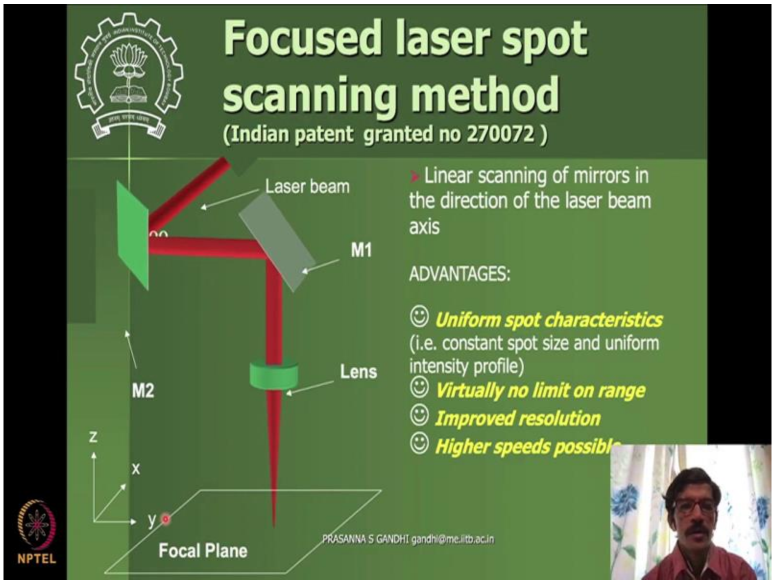

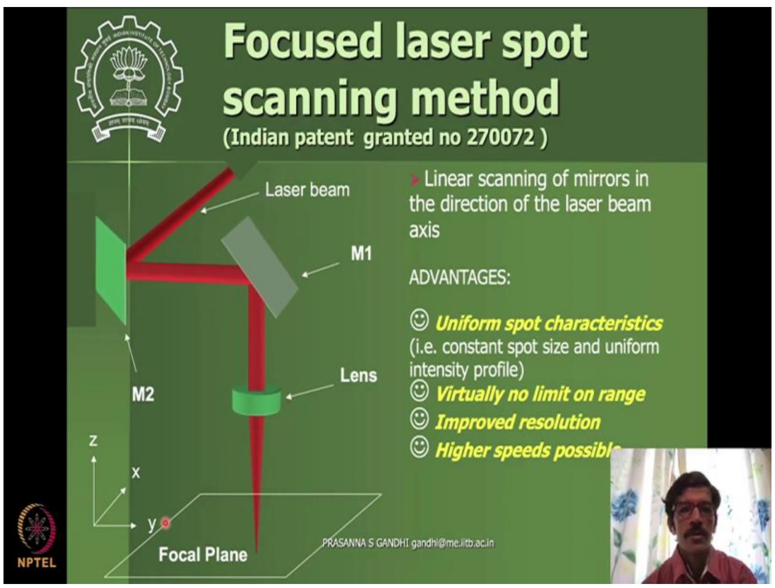

Then finally we propose another method which we could get in Indian patent on is scanning the laser beam along with the mirrors. So, mirrors also get scanned in a way that in a linear fashion. So, previously we are moving only lens in a linear fashion but now lens and mirror 1 they move in a linear fashion and you get is laser beam scan on the surface. Then you can see that the focal plane all the time the laser focus remains exactly at the focus, laser remains exactly at the focus entire point on this plane and the same thing can be done with the other direction also.

So, X and Y direction scanning can happen in this kind of fashion. So, there are many advantages that your spot characteristics remain uniform so you can increase the range now whatever like dimension you want to scan you can get that kind of scanning done and there is no that is why there is no limit on the range and you have improved resolution happening with this kind of a scanning system.

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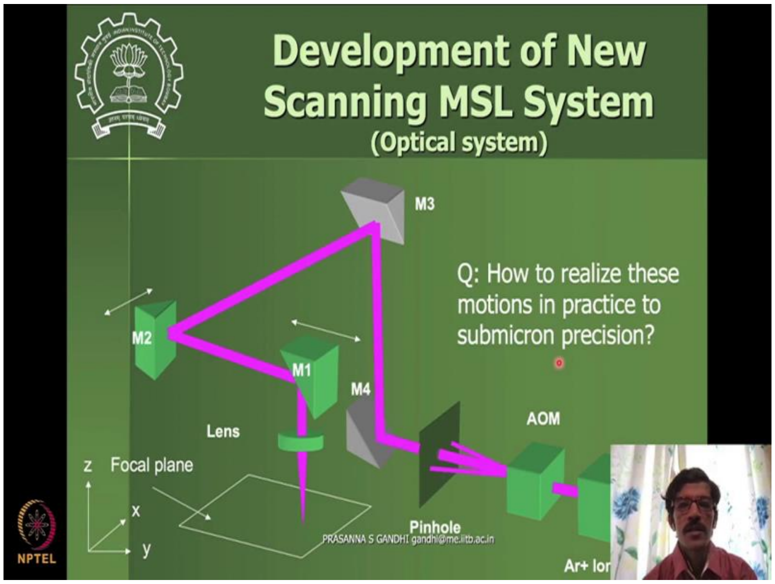

So, now to do the scanning in a very precise kind of a fashion then we need stages. So, the entire system would look something of this sort. Where your beam is used and split by using this acousto-optic modulator which will which is basically a switch you can imagine that if some signal is given electrical signal is given to the switch then it will switch on the light and switch off the light in a matter of like few nanoseconds.

So, that is what like acousto-optic modulator is designed for. Then your beam is getting focused on these fixed mirrors first to kind of just like there just the steering mirrors and then you have actually mirrors which are in motion. So, these are the mirrors that can be used for some adjustment and alignment and those kinds of purposes.

So, this is how entire system will look like and you will need to move now these mirrors M1 and M2 to have the scanning happen, mirror M1 and lens together will move and then mirror M2 will move in a perpendicular direction. To this laser beam, with integrator like mirror 1, mirror 2 and lens unit together will move in the perpendicular direction. So, that is how the X, Y scan would happen. So, these are the two perpendicular direction motion that will be happening for the mirrors. So, now to get to this with the sub-micron kind of a precision, that is what I was talking about we need some kind of a compliant mechanism design that we saw.

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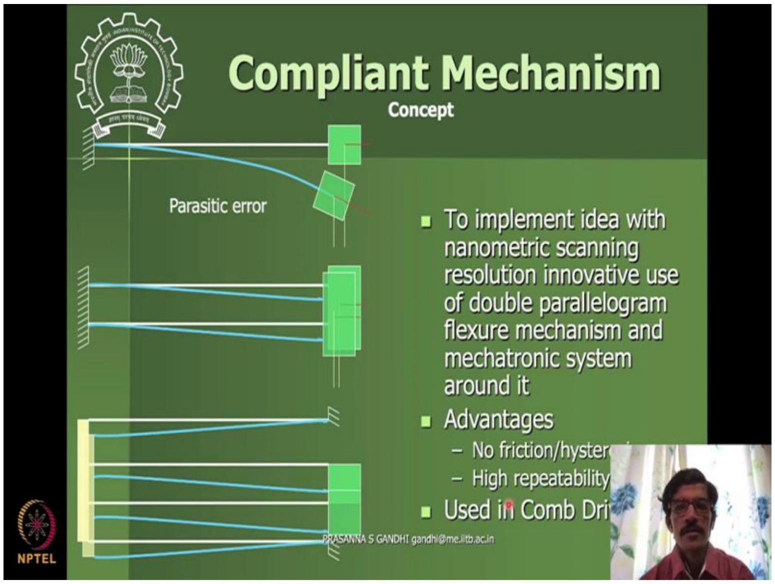

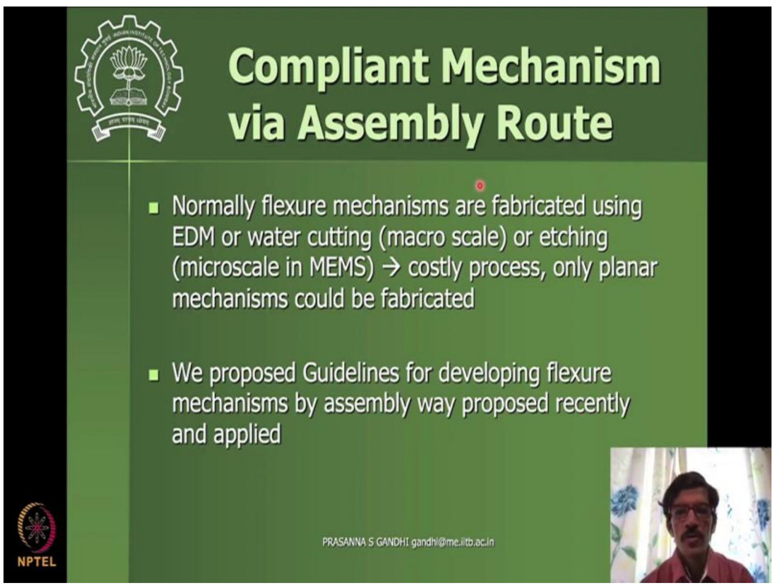

So, you remember this concept we talked about. You have you want to this block by using some kind of a compliant mechanism we start off with simple kind of a scale or cantilever beam which is fixed at one end and you give the deformation the beam moves in the vertical direction, but there are these parasitic errors that there is a tilt here and there is this kind of a parasitic error. Then you add one more beam to that system and then you will find that this will be now better that it has no tilt that is happening to these blocks, but there is still this kind of a parasitic error exists and then you go for the system where you have this block moving in perfect straight line because of the symmetry.

So, there are some more integrity about the system which will not get into a whole lot of kind of research has happened over the stages to see how their analysis how they their behaviour is especially for long deformation a large deformation. So, this idea we implement by using developing this compliant mechanism or reflection stages.

And these are now further manufactured by using the assembly route. Instead of doing like typically people fabricate such mechanisms by using some kind of a monolithic block cutting out of that in water jet or some kind of EDM kind of a machining, but we proposed a new way of doing it by assembly routes so that we get that mechanisms which are also can be built in the third dimension and we save some kind of a costly processes. So, this assembly route is not very straightforward if we start like doing what we have fundamentals that are known in mechanical engineering that you assemble two pieces together you need two pins to locate them with respect to each other.

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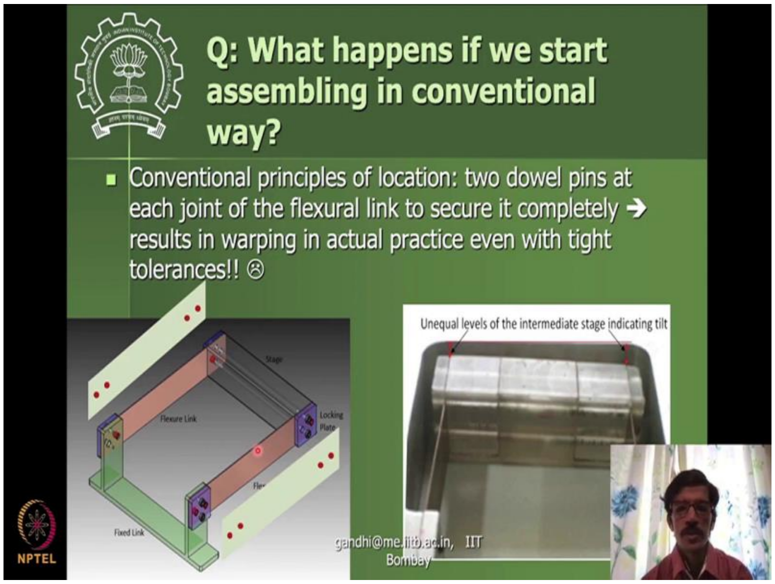

We start doing that and you will find that this mechanism would conventional principles if you do this mechanism will get warp. Actually, if you see this is a picture of warp mechanism all the pins are put in all the places and this warping happens and this warping happens because these beams have a tendency to flex or the tendency to move. So, depending upon like no small tolerances even if they are very very small you will have this tendency for the internal forces to be created when you put these multiple pins.

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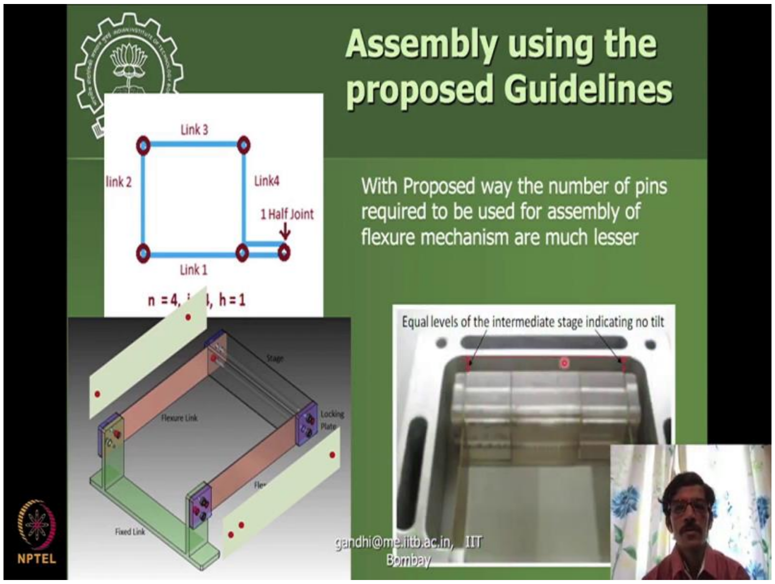

So, we have come up with guidelines which will formal like guidelines which will resolve this issue and give you a number of things to be put at places so that the mechanism eventually becomes unwarped. There is so the same mechanism same tolerances on the pins and dimensions are there but now in this case a mechanism is not warp. Because of the particular kind of way of assembling. So, we have some publications on this idea.

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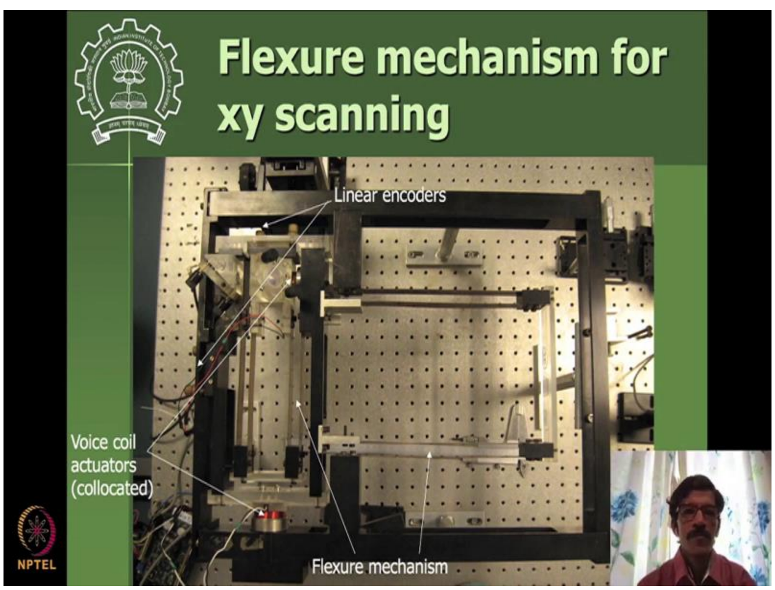

So, we use that and like now we build complete flexure stage and this is like a complete scanning system. So, this is one stage is carried by the other stage. So, this is a say X motion stage here and then like no you have this Y motion stage inside this and here there are some kind of mounts for the mirrors and here there is a mirror mount and the beam is getting kind of steered by these mirrors and it is going finally on another stage or Z stage tank which will be getting move in up and down direction for the different layers so that you want to prepare in the 3D printing.

So, this is a system that is now built and now this flexure compliant mechanism stages are available here you can see that these are some of the mechatronics components here where you are mechanical compliant mechanism stages are integrated with this voice coil actuators and then there are linear encoders to do the job.

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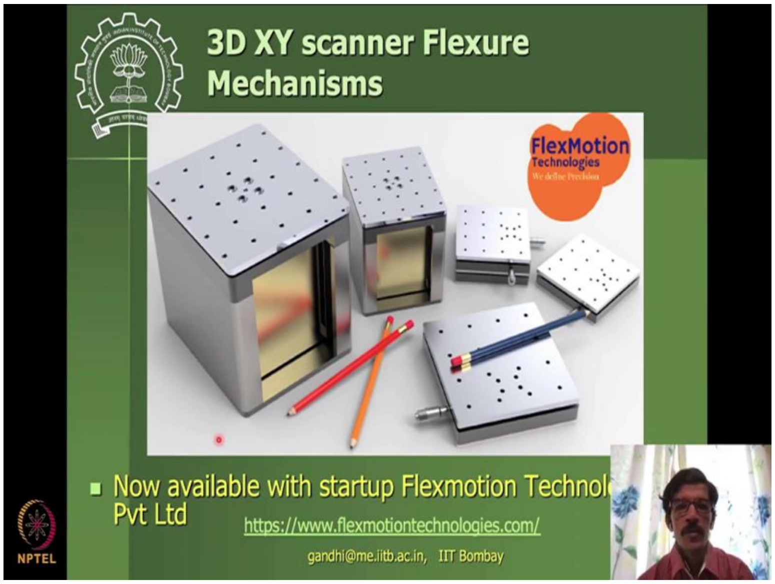

Then we have now this complaint mechanism stages manufactured by this company called Flex motion technologies is a start up from here at IIT Bombay and this they are now available for many different applications.

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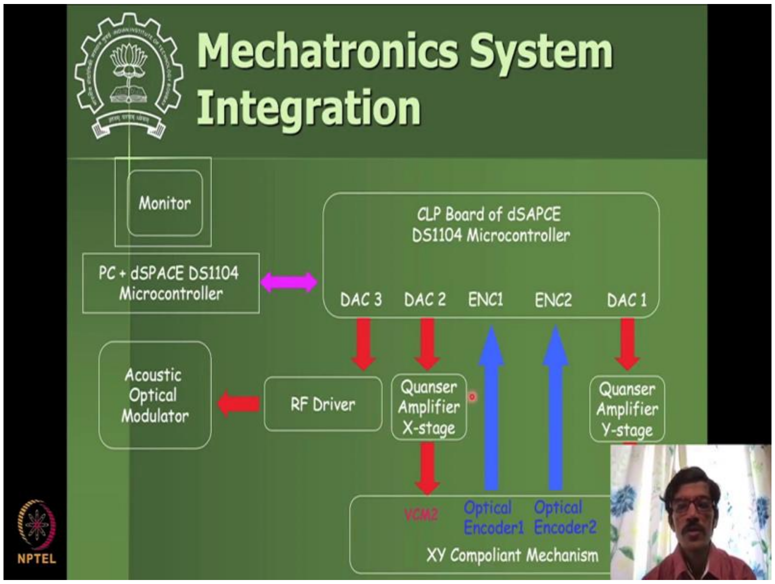

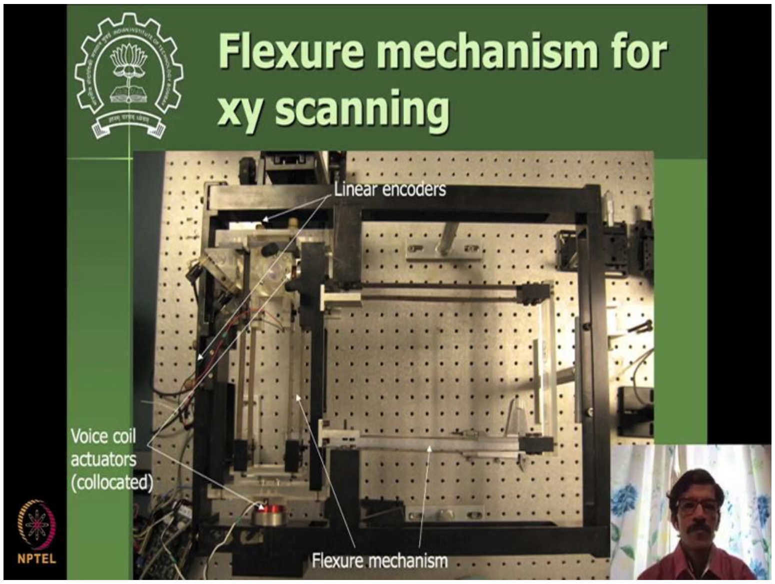

So, now we integrate this mechatronics system for the 3D printing around these. So, we have this data aquation system called dSPACE. So, this is 1104 particular version of this dSPACE company microcontroller and they provide basically this kind of hardware interfaces as a Simulink blocks in the MATLAB Simulink file.

So, these are now extra blocks coming in the file. So, what you can do is basically whatever controllers that you built by Simulink or any other kind of way in MATLAB they can be very easily ported to a hardware system. So, that is the ease for a very fast prototyping you can do this. Although this is a costly kind of affair, but once the system is available, you can do a lot of mechatronics system prototype testing very fast.

Because you do not need to worry about programming a microcontroller because these are already available as block sets in the Simulink block you can just put together those blocks and you start programming, you start building the thing and all the things programming will happen automatically for this microcontroller.

There are they have developed this kind of the block sets which will compile and rebuild the microcontroller program the way you have maybe if you have taken hands on training you have written some program in TIVA those programs will be built now by a compiler in real time system of a MATLAB.

So, this is a very handy tool for especially those who are mocked up by this microcontroller programming business. And this is good like fast prototyping way of doing things. Then in this board do we have now we need to identify what are the channels that we need to use. So, we are using here the digital to analogy converters two converters for this driving X and Y stages DAC1 and DAC2 which has this amplifier that is used.

So, this again so as we have seen for any high current or high power application you need amplifier to be there to interface with the microcontroller. So, here we are using this Quanser amplifier for X and Y stage voice coil driving. Now this is where we are using here voice coil as we have seen here instead of motor we have this voice coil it is just a coil and a magnet assembly together and these are noncontact actuators they are guided by these compliant mechanisms and only the magnetic force is applied when the current is passed through this coil, non-contact kind of fashion force no friction is there in the system.

Then you have this encoder which are kind of sensors in the system which are reading the data we have seen a lot about encoders how they work and how they can be programmed and things like that. So, these are optical encoders but now they are linear kind of encoders again they are non-contact and so entire system has no friction and that is what gives a way for positioning them with a very very fine accuracies and then we need this laser to be switched on and off at certain locations.

So, depending upon what you are scanning, so, this is an RF driver for driving this acousto-optical modulators. So, this entire thing comes as one unit acoustic optical modulator will come along with its driver and you have some kind of a DAC pin which will control the laser intensity digital to analog kind of a converter between dependent this analog voltage your laser intensity will be will be controlled. So, this is a system that that you need for operating laser on and off depending upon X Y position so, that your scan can done in a manner that you like to. So, there is one more kind of DAC that will be used for Z stage for giving the Z dimension or like third dimensional motion.

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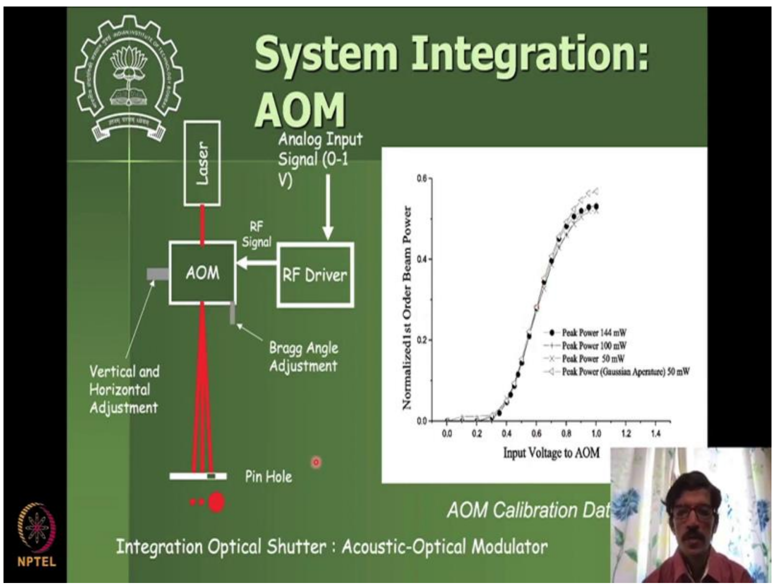

So, this I let me integrate then typically you start with the testing of the systems and like characterizing the system. So, this is how we characterize the power of the beam that is coming out as input voltage to acousto-optic modulator is changed. So, this you get a laser spot which is now changing its it can be changing its power depending upon what is the voltage that is given as input. So, if you want to switch off the voltage you gave 0 and if you want to switch on the beam at some certain point you gave some something like 0.6 volts or something like that to kind of get that much intensity to for the laser beam.

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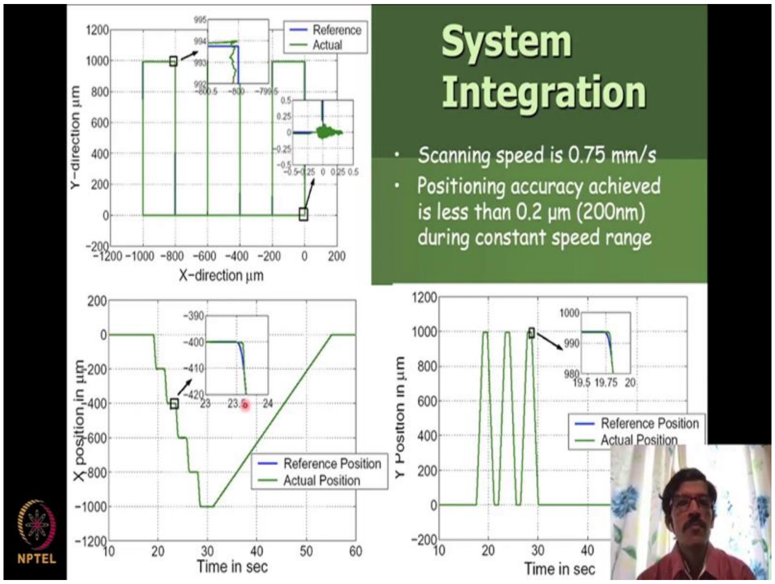

Then we test the X, Y stages at different different scanning speeds and here like the scanning speed is about 0.8 mm per second we have gone now for the stages which are running at 15 mm per second or 10 mm per second kind of thing and currently we are building other kind of a resonant kind of scanning stages which are going to the speeds as high as 300 mm per second so, that with keeping the same accuracy and you see that position accuracy achieved here is about 200 nanometre.

So, this is how one can develop like the system which can give you the accuracies which are sub-micron level when you want to do like a micro printing or micro scale printing you want to do. So, with this kind of accuracies here you are able to kind of get your components really fabricated really nicely.

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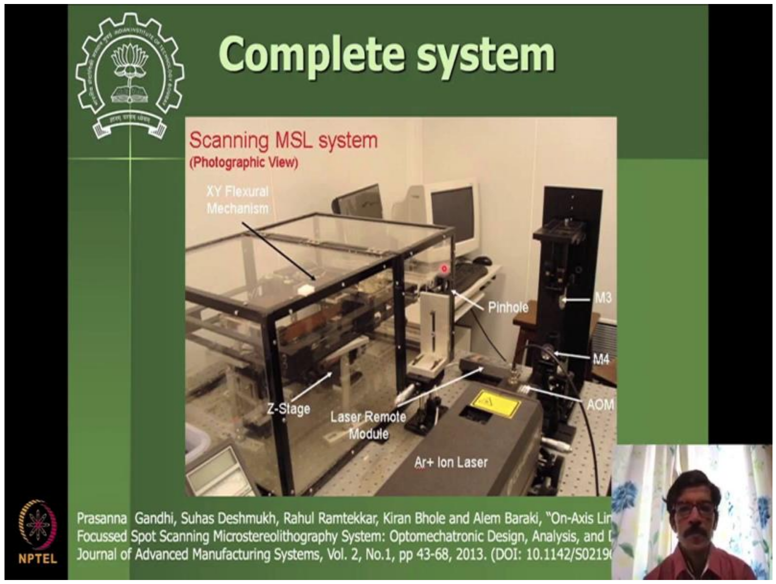

So, this is like a entire complete system developed we one of my first PhD students Suhas who was working on this in the early days now we have I think the fourth prototype of this micro printer coming up in our lab which is having very high speed and high range of component that can be fabricated.

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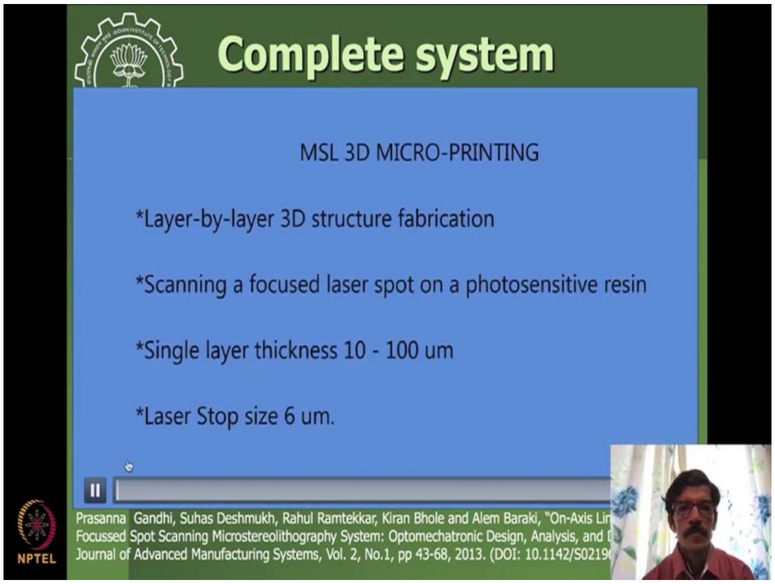
Complete system
MSL 3D MICRO-PRINTING
*Layer-by-layer 3D structure fabrication
*Scanning a focused laser spot on a photosensitive resin
*Single layer thickness 10 - 100 um
*Laser Stop size 6 um.
Prasanna Gandhi, Suhas Deshmukh, Rahul Ramtekkar, Kiran Bhole and Alem Baraki, "On-Axis Lin
Focussed Spot Scanning Microstereolithography System: Optomechatronic Design, Analysis, and D
Journal of Advanced Manufacturing Systems, Vol. 2, No.1, pp 43-68, 2013. (DOI: 10.1142/S0219
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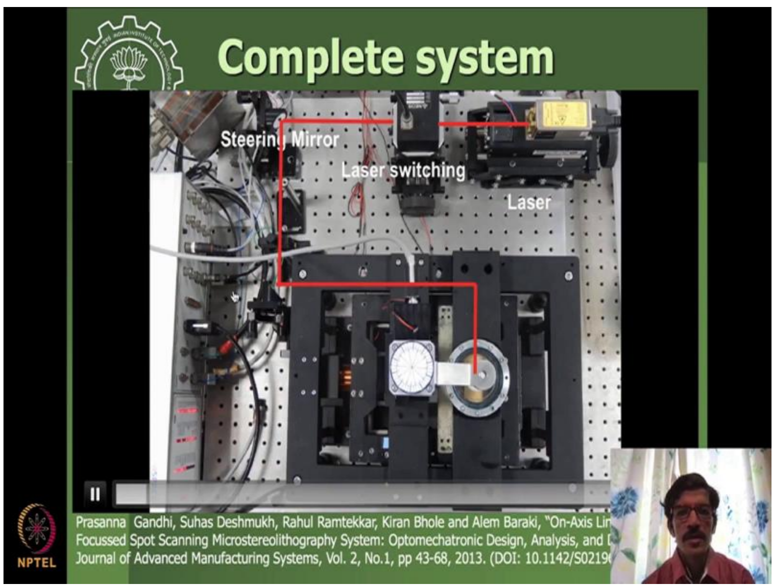
Complete system
Steering Mirror
Laser switching
Laser
Prasanna Gandhi, Suhas Deshmukh, Rahul Ramtekkar, Kiran Bhole and Alem Baraki, "On-Axis Lin
Focussed Spot Scanning Microstereolithography System: Optomechatronic Design, Analysis, and D
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Complete system
Z Stage
X stage
Y stage
Prasanna Gandhi, Suhas Deshmukh, Rahul Ramtekkar, Kiran Bhole and Alem Baraki, "On-Axis Lin
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So, we can see this little video of the entire system here now. So, you can maybe we will show you in the next video then we have another video which is coming up here. So, this system has these like a next version of the system you can see here this is the electronics there are interfaced and then there is a mechanical scanning system and this mechanical scanning system is start scanning X, Y stages by using this compliant mechanism and voice coil kind of actuator and you can see there is a this is a tank here and then there is a Z stage on the top of this so this Z stage is what is carrying the component up in the Z direction.

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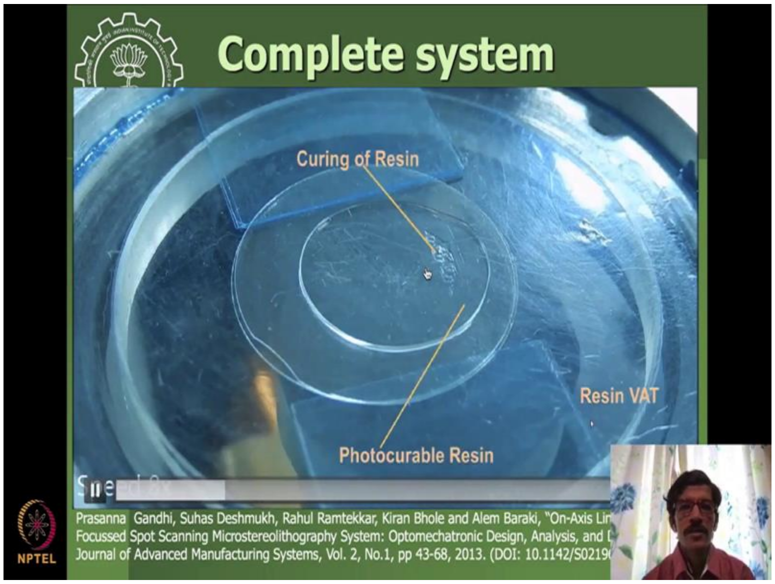

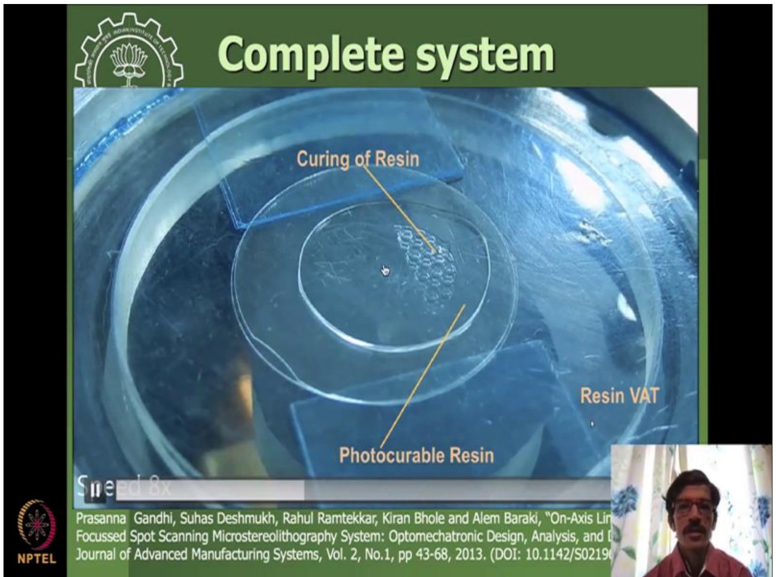

So, once the component first layer gets printed like this. So, this is a layer getting printed. So, there is a continuous motion in the Y direction and stepping motion in the X direction that is happening here and this component gets slowly slowly developed here. So, this is like a hexagonal kind of a comb kind of a structure honeycomb kind of structure.

So, this structure is getting developed now and then multiple layers of such structure can be developed right now, we have kept only for the demonstration purpose the Z stage is not seen here. But this layer once it is fabricated, it will be pulled off the bottom region mat and then the next layer of the bottom resin will come between the fabricated layer and bottom surface. And once that happens then you will have next layer preparation done and next layer can be fabricated in similar kind of way.

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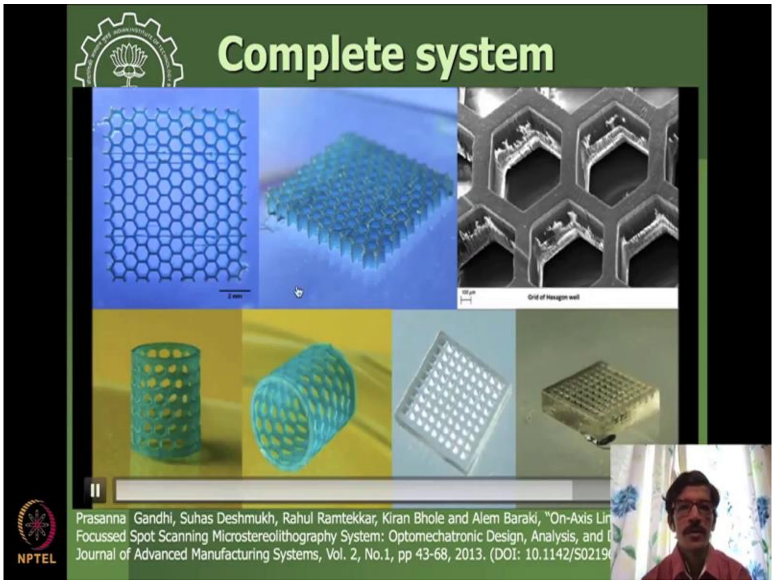

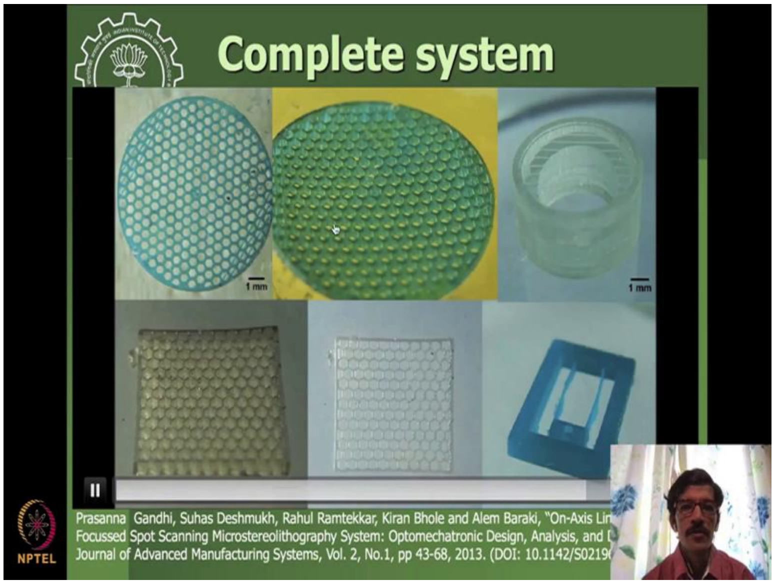

So, let us move on to these and see some of the components which are fabricated now with this printer. So, this is now doing the layer by layer it is moving in it is pulling the component up and then again going down and positioning itself to a level where a very thin layer of the liquid is pieced between to component and bottom of the what about the resin tank like that multiple layers it will start fabricating these components and you can get this components fabricated like this. So, this is a honeycomb structure that you saw fabricating fabricated and multiple layers so you can get like a thick structures like that. So, many thick structures which are very intricate geometries at micro scale can be fabricated.

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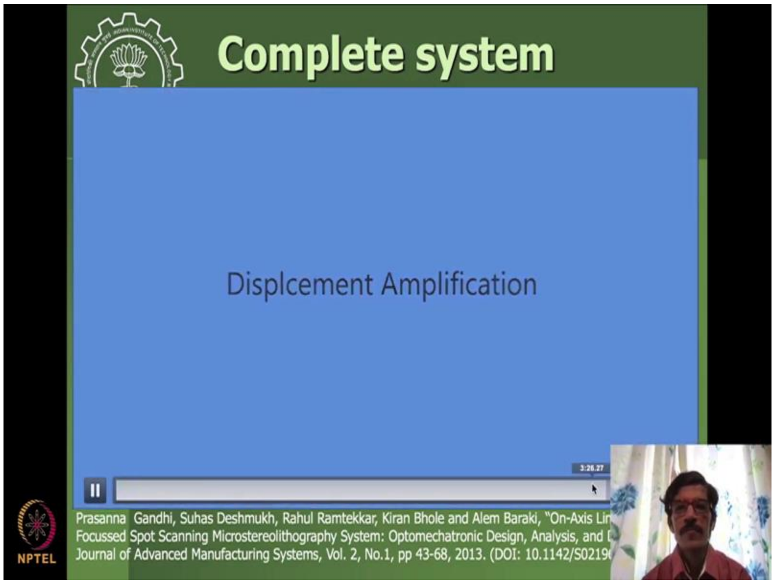

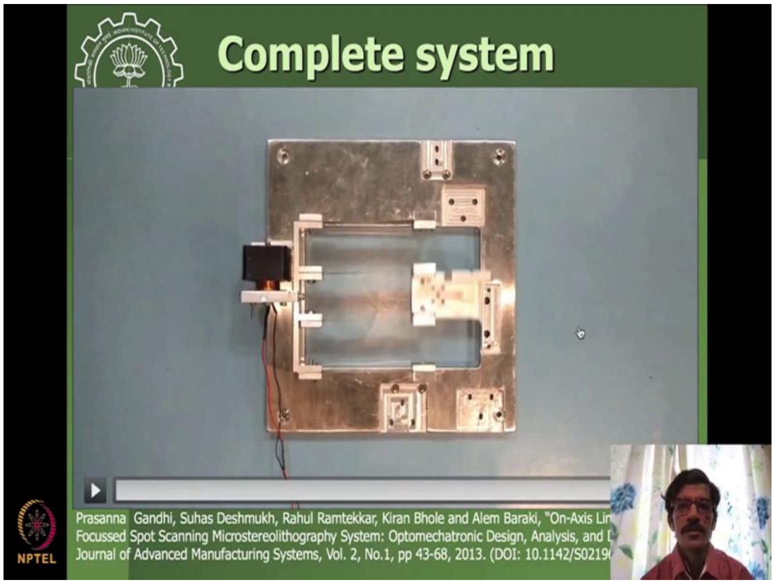

Complete system
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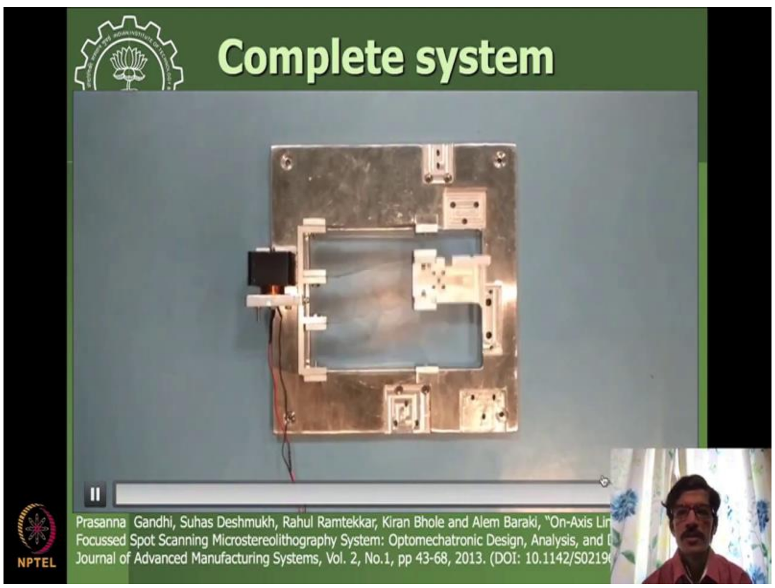

Complete system
Prasanna Gandhi, Suhas Deshmukh, Rahul Ramtekkar, Kiran Bhole and Alem Baraki, "On-Axis Lin
Focussed Spot Scanning Microstereolithography System: Optomechatronic Design, Analysis, and D
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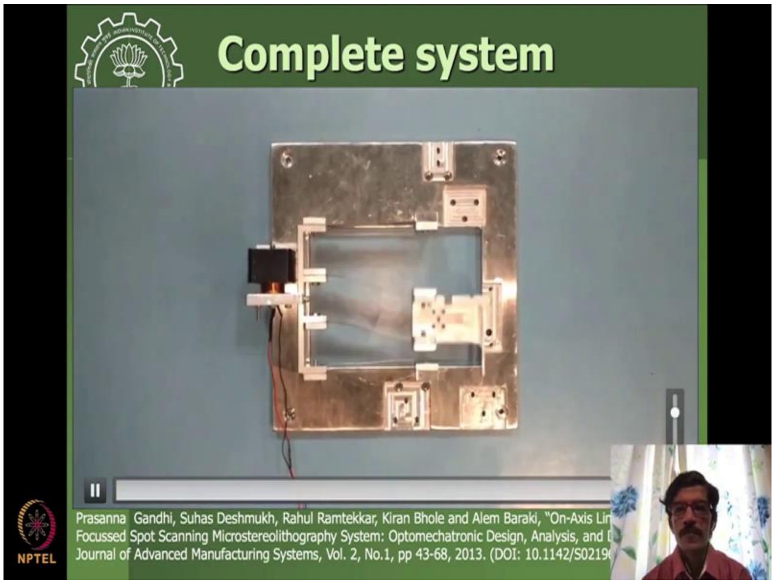

So, now we are using this new concept of resonant vibrations to do now the similar kind of displacement or scanning at a high speeds.

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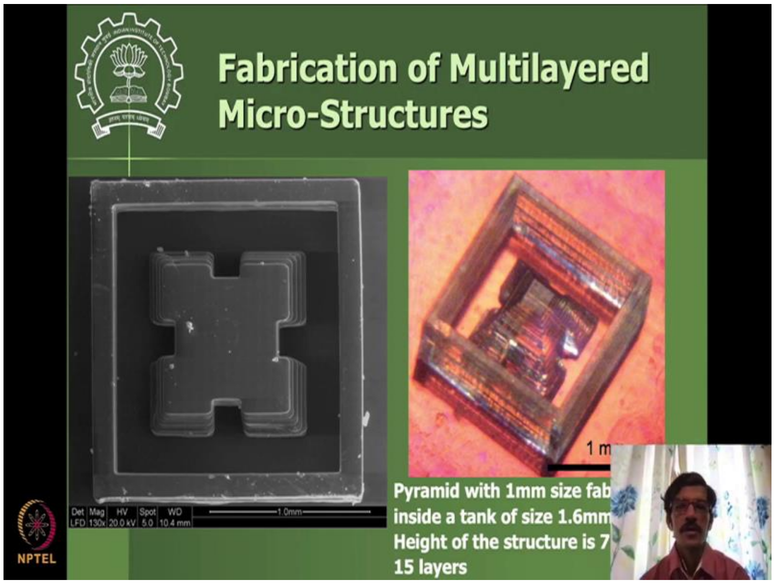

3D High Aspect Ratio Microchannels
S3400 10.0kV 40.8mm x20 SE
2.00mm
S3400 10.0kV 44.0mm x50 SE
High aspect ratio microchannels
PRASANNA S GANDHI gandhi@me.iitb.ac.in
NPTEL

More Fabricated Microstructures using Proposed Way
Det
LFD
PRASANNA S GANDHI gandhi@me.iitb.ac.in
* Gandhi P.S. and Deshmukh S."A 2D optomechanical focused laser spot scanner: analysis and experimental results for microstereolithography," Journal of Micromechanics and Microengineering, 20 (2010) 015035.
NPTEL


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LFD 150x 20.0 kV 5.0 9.6 mm
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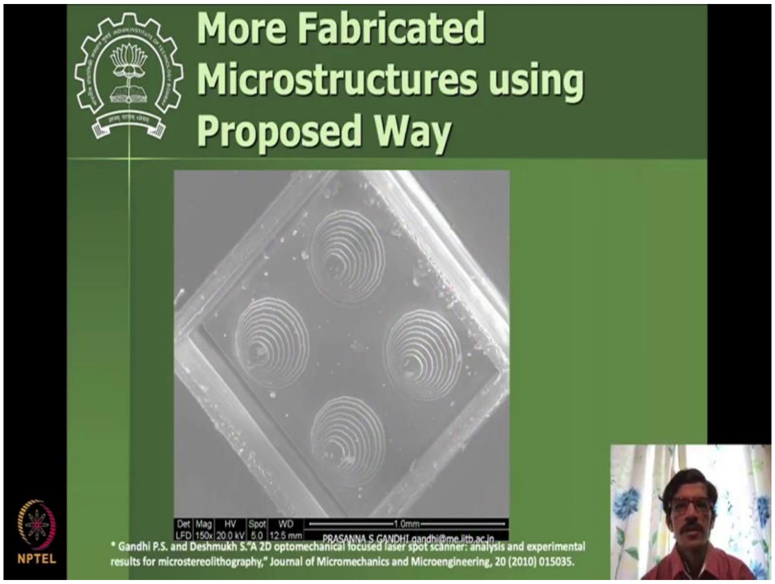

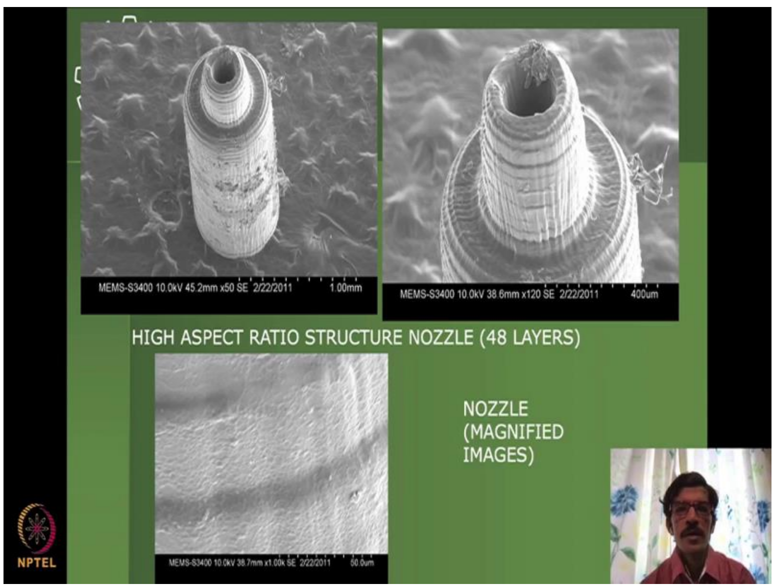

So, let us move on from here to see actually the structure is fabricated these are like different different kinds of structures that are fabricated by these you can see this scanning electron microscope images of these structures which are showing like very good dimensional accuracy with respect to the accuracy that we wanted to have. So, one can find, fabricate this high aspect ratio micro channels and many different kinds of structures that can be fabricated. So, I am just displaying the structures to see. So, they one can have see this is a 48 layer kind of a structure so 48 times like Z stage has stepped up and you get this entire structure and inside this you can have whatever geometry of the nozzle that is needed can be realized.

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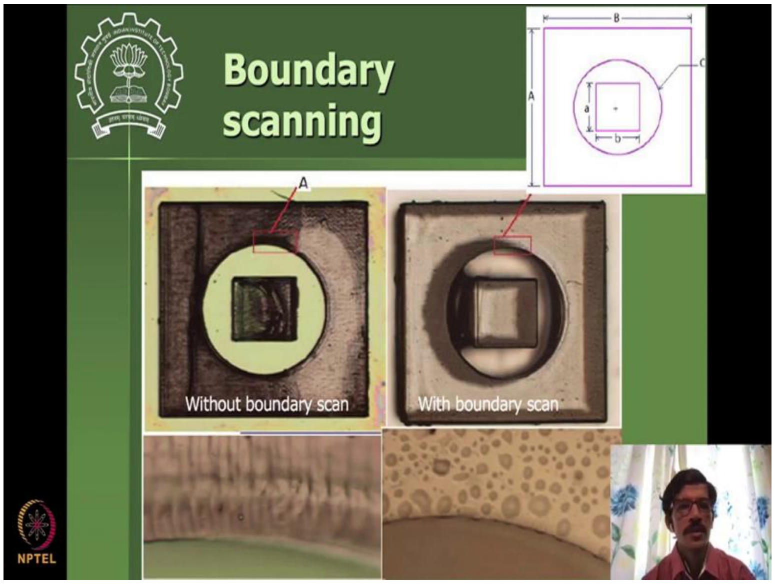

Then you can have a boundary scan. So, this is all what you say more kind of refinements are that are done based on the application requirements the basic mechatronic system remains the same like you have these X Y flexure based scanning stages.

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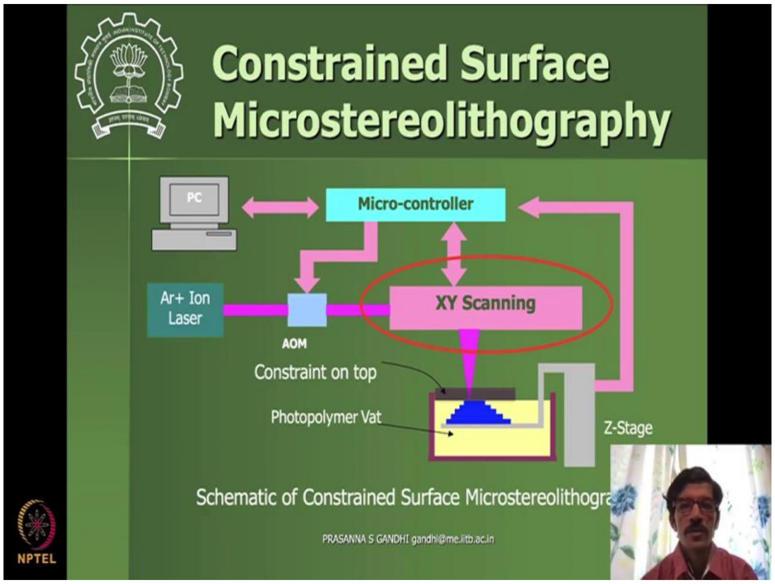

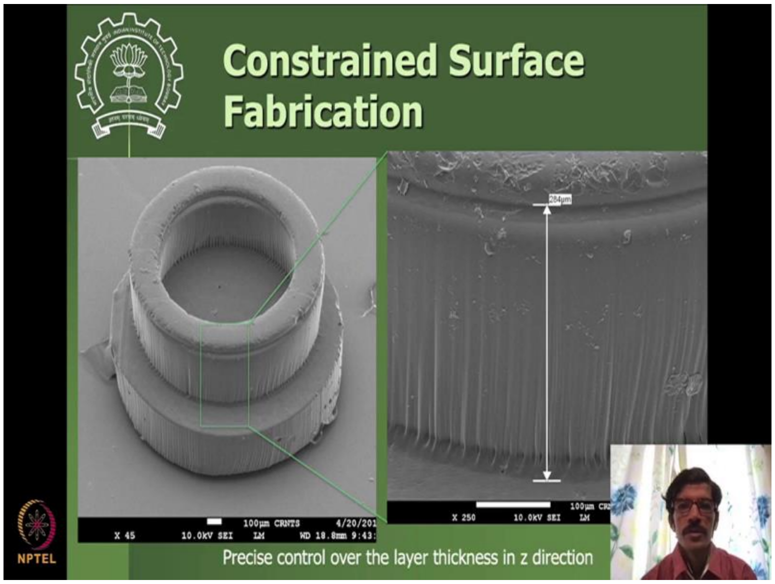

And there are some kind of interesting control algorithms that are needed to be used for this kind of scanning because you do not want to get into vibrations of this complaint mechanisms. If they start vibrating unwanted kind of a way then you will get you will start seeing the inaccuracies in your positioning.

So, those are all handled at the control level by designing some control strategies which are I would say unique to make sure that these vibrations do not creep in from the compliant mechanisms stages and still we achieved the job that is needed at a high speeds. So, this is that where like know lot of these modelling and simulation and final tuning of the gains those kind of activities will be coming in as we have seen in the course

So, this is like constraint surface kind of fabrication where you are now top surface is constrained instead of so, what we saw in video was actually this the top surface was constraint, but will not the Z stage was like upside down it was Z stage was coming up rather than going down in this this kind of a way.

So, this constraint surface is can give you very high accuracies in the layer because the layer is constrained between two surfaces and that these surfaces can be maintained at a desired accuracy. Unlike open like no without constraint surface you will have open layer liquid layer and liquid layer top surface we do not know whether it will have exactly the same dimension as the thickness that you want to get cured.

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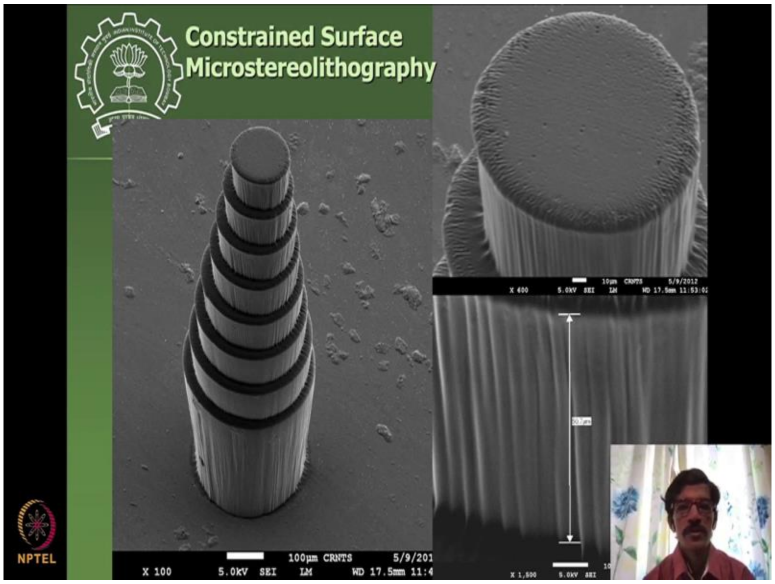

So, this is constrained surface micro stereography gives you quite good accuracy in the component produced.

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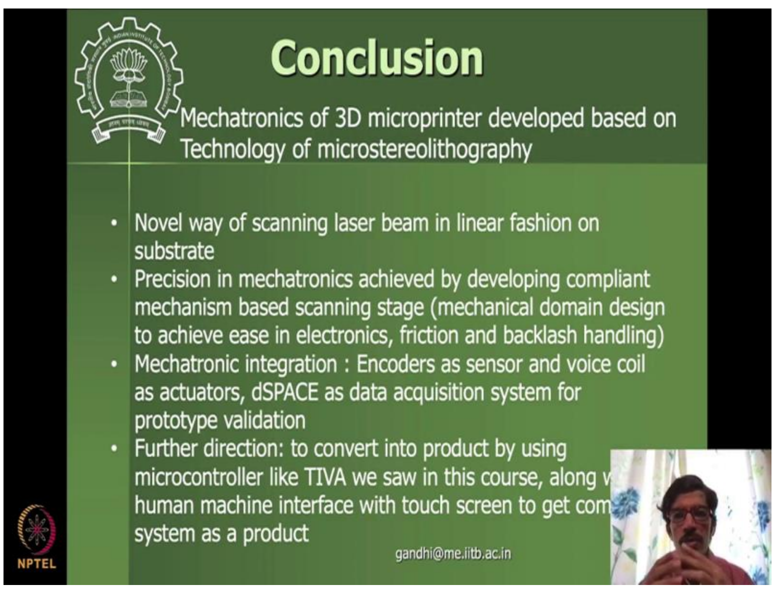

So, this is conclusion for this part where like know we see some novel way of scanning laser beam in the linear fashion on the substrate. So, like that you can think about your own idea of you some kind of a way some activity to be done once it is that idea is there at your in your mind then you start putting things together around that idea.

So, we started off like know okay we wanted to do some high accuracy kind of thing then this idea came up of this new way of scanning laser beam and then we started putting things around that idea, this how like know you can see this mechatronic system can get designed and built in a very nice way and whatever like know some kind of you will find some things come a long way like say for example in our case we found that we how do we assemble these beams very easily there was one of the important kind of aspects.

So, that we resolved by like know formally studying like how these assembly is behaving and so the small experiments very crude experiments help in in getting these ideas generated in a faster pace. So we started assembling and you find okay look, you have this problem then we study this problem a little bit more mathematical details and then give a solution and then so going back from theory to the practical and practical to the theory like that kind of way of doing things help a lot.

So, that is why we started out this course with looking at actually the practical systems that made things work. If you remember with CD ROM and scanners and other stuff more, you have worked with those systems and understand what is going on in that it will help you to design like a new things much better way.

So I encourage you to really look at these some of these systems like CD ROM or hard disk drives which are gone you can just open them up and check out okay what are the components that are existing and why they are there like that, as we did this analysis you can carry out with many other kind of devices in the similar kind of a way maybe your washing machine or like any other kind of tape recorder like a lot of these devices we may find available at a throwaway price or they are gone without any cost people will be happy to give you to explore.

So, see, this is the first kind of step for developing this product like now we want to get into the product then the further direction is to that convert this kind of idea now with the microcontroller like TIVA see we have used the dSPACE as a data acquisition system we cannot use it for actual product, this is just for the sake of prototyping is very costly system and it is it comes with MATLAB MATLAB, you do not know you do not have commercial licenses of MATLAB for you cannot ask your customer to do that.

So, this dSPACE is not a thing for actually find the final product for the final product you need to go back to microcontrollers that we have seen in this course like TIVA where like you start programming these to get your embedded system completely done. So you need to kind of see okay well what are the things competence I need these drivers I need all these things can be integrated in the electronics box with some kind of a microcontroller the choice now we can have based on these course we can have different choices possibility the many places you may need this human machine interface with some kind of a touchscreen or something to operate the machine.

So this this kind of a product will be so there are some microcontrollers which will provide you these. So in the raspberry pi for example, there is some possibility in TIVA also there are some other kind of versions which are available in Texas instruments other microprocessors which will which will offer this kind of interface. And then we can program that to get the complete system as a product.

So, then like this is this comes to you as a product where there is some touch screen and you have some kind of a pen drive on which you can just put the data of the what is to be printed, and it will start printing, the way we use our 2D printers in home, you can have these kind of a way 3D printer as a product can be produced. So, this is first part of the thing will stop here for now, and then we will continue our discussion in the next part about some other kind of a case study system. Thank you.