**Mechanical Measurement Systems**
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**Lecture - 38**
**Flow visualization**

Hello, I welcome you all in this course of mechanical measurement systems and today we will discuss the flow visualization. Flow visualization is important because, we do not have analytical techniques to find the flow field in a in a in system where the fluid flow is taking place. So, in absence of these analytical techniques some experimental techniques are used and if we use experimental techniques where interference of the flow is interference with the flow is taking place, then it will change the flow field.

So, there are certain techniques and these techniques are optical techniques of flow visualization right. So, today we will start with Shadowgraph and then we will discuss the Schlieren, Interferometer and then LDA Laser Doppler Anemometer. So, these 4 techniques we will be discussing in this chapter, in this lecture. Ah first of all we will discuss about the flow visualization, how the visualization of flow is done.

For example, there is a channel or the fluid flow is fluid is flowing perpendicular to this port.

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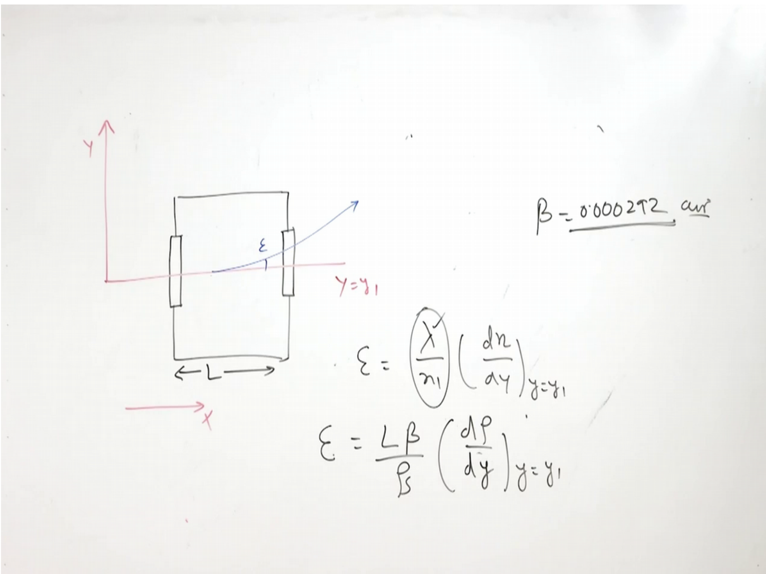

So, there is a channel, right and across the channel there is a glass window right and a pencil of light is entering from this side or a ray of light is entering from this side and going through this channel. And there is a uniform I mean there is no density variation inside this channel. When there is no density variation, this without deviation this pencil of light will pass through this through this test section. And here Y is equal to y1 and this is Y direction and this is X direction.

Now, suppose there is a variation in density, when there is a variation in density this ray of light will be deflected right and this is known as epsilon ah deflection angle. And deflection angle can be expressed as epsilon is equal to lambda by n1 dn by dy, y is equal to y1. n is the refractive index and n1 is the refractive index right and lambda is the wavelength ok, wavelength of the light. And it is equal to L beta by rho s, rho s is the density of the surrounding fluid d rho by dy, y is equal to y1 because the change in the refractive index d rho by dy ok.

So, derivative of a refractive index with respect to y is equal to the derivative of density with respect to y. Because this change in the refractive index is a function of change in density of the medium. Here beta is a cost and dimension less constant and beta is equal to 0.292 for air, it also varies from one fluid to another fluid. For air it is 0.00292 right and this is the angle of deflection epsilon. L, this is the L, let I think rest of the values are with us, we do not know this d rho by dy right.

Now, these are the basics which are used for flow visualization techniques in the flow visualization techniques, let us start with the Shadowgraph.

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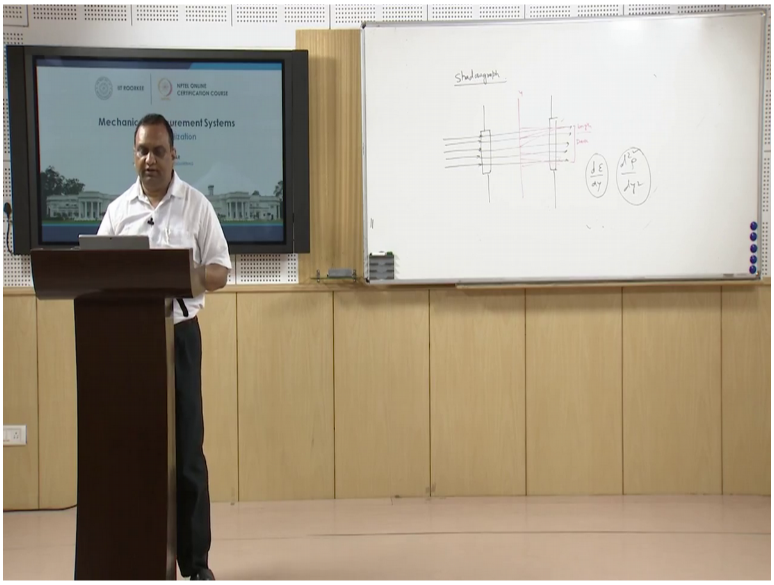

Now, in Shadowgraph let us take the same test section. There is a viewing window right and the ray of parallel lights parallel the rays of lights light is entering this channel and there is no variation in the density, then they will simply pass through this right.

Suppose, there is a change in the density of the media here and if there is a there is a change the density of the medium, then these line will tend to converge or diverge depending upon the change in density. So, instead of getting lights like this in implant this is a Y plane, some of the ah ray may converge and some of them may diverge. And we will be getting not uniform illumination on this side, some dark spot and bright depending upon the change in the density whether density has increased or density has decreased.

Now, this variation in the figure is the image is known as the Shadowgraph and very good example is of Shadowgraph. this process of this Shadowgraph is where you take a hot plate when hot plate is heated there is a variation in density from the surface of the plate to the top.

So, the air which is in contact with the surface of the plate is at lower density, here when you are moving up the density is gradually increasing. If you look just at the level of if you keep your eyes at the level of the hot plate, you will find. You can see the convection currents, with the naked eye you cannot see but, if you put your eyes just at the level of the plate, you can see convection current moving us. That is also a sort of Shadowgraphy, I mean that is a very I mean primitive or 2 type of Shadowgraphy, but this is also how I can explain you the Shadowgraph.

So, the hot plate I mean when you are looking at the hot plate at the at your eye level, then when you are when you are seeing the convective current so, that is a one type of Shadowgraphy. And Shadowgraphy has many applications in the fluid flow; especially where there is a change in density for example, there is a shock wave. If there is a shock wave then through Shadowgraphy we can see the movement of the fluid or the fluid the flow visualization or disturbance in the flow the due to the shock waves.

So, that is one technique of flow visualization. Ah now, the illumination in the shadowgraph it depends upon the it depends upon the change in deviation or epsilon with respect to y. Higher is a change, more is the contrast between dark and the bright spots or more better or better visualization is there and this change is equal to the second derivative of density with respect to y.

Now, after Shadowgraph I will take up the Schlieren. Schlieren is a very popular and reliable technique for flow visualization, Schlieren SCHLIEREN.

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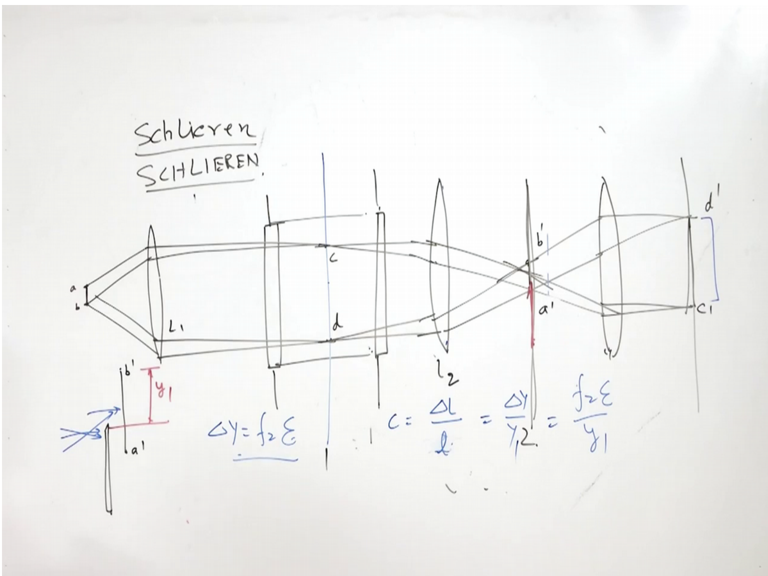


So, this is a very popular technique of flow visualization. In case of Schlieren there is an object, let us assume there is an object a, b right and this object is the ray of light which is coming from this object is passed through a convex lens. So, there 2 rays, they are coming to l1 lens 1 right. After coming to the lens 1 and this is our visual section and flow fluid flow is perpendicular to this board. So, this is visual section and after this lens, it goes it the way it crosses in the middle of test section and they cross each other and come out of the test section. And then they pass through another lens l2, this is l1 and this one is l2. So, they will also cross each other and they will come to l2 right.

Now, after l2 there is a image formation and this is a plane 2, this is plane 1. So, plane 2 draw with different color, this is plane 2 and this is a lens. And after this lens because we are passing through this lens, they will change this path and they will cross each other at plane 2. And for now the form an image, now the plane 2 will come here when they cross each other then plane 2 will come here. So, plane 2 will come here, they will cross each other here and the plane 2 will come here right and this is plane 2 and plane 2 that because this is a, b so, this is real image a dash, b dash.

Then again it will go to another lens that is l3 and after l3 they will converge and form a image suppose this image is c, d then this will be c dash, d dash. So, arrangement is optical arrangement is more or less like this I am repeating. Now there is an object a, suppose there are 2 sources not an object there are 2 sources a and b, they are starting from here, after going through a lens they are converging at plane c and d right. And the image of plane c and d is formed on the screen in the form of c dash and d dash right using 2 lenses further 2, further 2 lenses.

Now, we can easily see I mean I mean visualize the fluid flow. Now there is a change, now there is a change in the density of the fluid, that is one thing. Second thing is if I put in knife edge here, if I put a knife edge here some of the rays will be obstructed and this image will become faint. I will amplify the knife edge here it is going to be like this, there is a knife edge right this is your b dash and a dash image, b dash and a dash right. And this b dash and a dash is partially covered with the knife and the part of the b dash, a dash above the knife edge is y1 right.

Now, when we are putting the knife edge this image is becoming faint. Now, there is a change in the density in the flow field. When there is a change in the density in the flow field then the deviation of the rays will take place, the deviation of the rays will take place those who are straight due to change in density they will be deviated from the path. And this knife edge will be obstructing the rays I mean those rays also which it is not suppose to abstract. Because, ray which has to be which was earlier which was passing over the knife edge now it will be obstructed by the knife edge right.

Or this is also possible the ray which was earlier obstructed by the knife edge will go over the knife edge. In fact, the presence of the knife edge will create contrast here contrast to the image. And this contrast is further and this contrast in the image will further enhance the visualization of flow, we will further enhance the visualization flow inside this channel right.

If we want to do certain mathematical analysis then this delta Y delta Y is equal to f 2 epsilon. epsilon is the angle and f2 is the focal length of this length so, of this lens f2. And contrast can be defined as the contrast on the screen can be defined as the ratio of or it is the it is a fractional change in illumination with general illumination.

So, contrast is the fractional change in regulation, contrast is high means fraction change in regulation is high. It may be on the darker side or it may be on the brighter side or it is going to be delta Y over phi ok.

And then delta Y over y1 sorry delta y1 it will depend upon this right and that is going to be equal to f2 epsilon divided by y1. Earlier, we have written one equation if you remember earlier we have written one equation that epsilon is equal to lambda by n1 dn by dy, this y is equal to y1 right.

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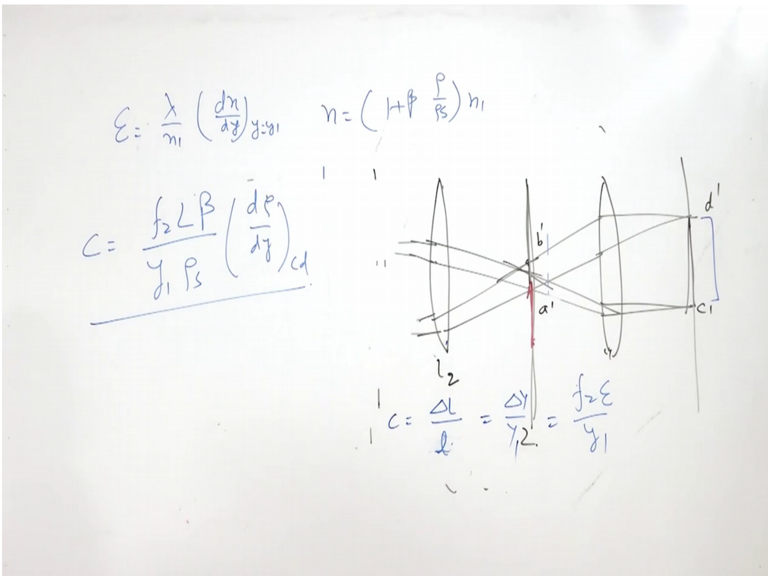

And we have also written n is equal to 1 plus beta rho by a rho s n1 right.

Now, using making use of this right making use of this we can write the contrast as contrast as I will rub this off, it is not required. So, I will we can write the contrast as c is equal to f2 l beta divided by y1 rho s, it is density of the surrounding d rho by dy at cd. cd I have rubbed off, yes that is cd somewhere here it was a plane in the test section.

So, this will give mathematically we can write this the contrast like this, but the Schlieren it has it has I mean just I have described you the working principle of Schlieren. Otherwise there is a lot of optics and the electronics in drawn nowadays. And we have very sophisticated instruments which used Schlieren and the do the flow visualization and flow visualization can be seen on the computer screen.

So, after Schlieren we will take up the Interferometer, there is another optical technique of ah flow visualization that is Interferometer.

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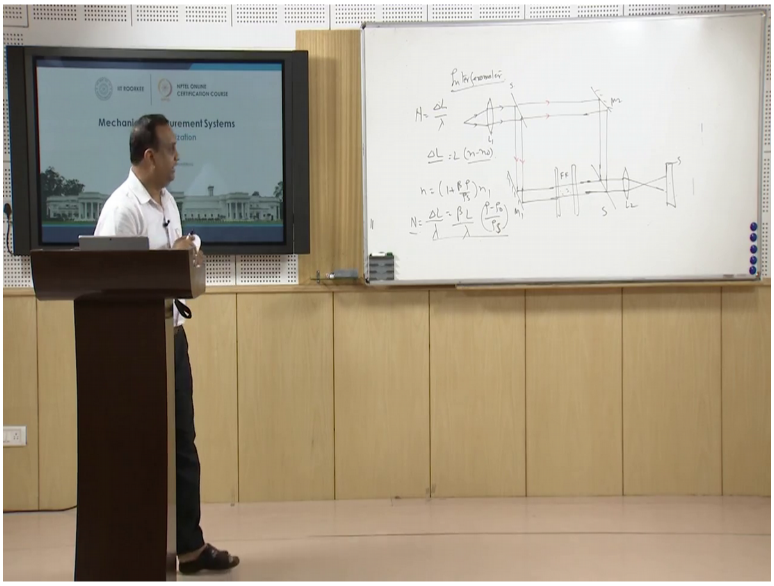

Now, Interferometer is Interferometer works on the ah on the on the principle that first of all if there is a change in density the path, there is a splitter. I will start with the diagram then I will explain it ok.

So, there is a light source and light source the light goes to a lens and this is lens l1 and then there is a splitter. So, this is a normal optical technique then through a splitter we have 2 rays and then these 2 ray will recombine. If they are traveling the same path then there is there has to be there will be no interference so, no fringes. But, if there is a difference in the path due to change in the density in the path then they are going to be the fringes and n lambda is equal to difference in the path travelled by 2 rays or delta x is equal to n lambda.

So, same techniques will be adopting here, there is a splitter. So, a splitter will split the rays in 2 parts, ones one part of the ray will pass through the splitter, another part of the ray will be reflected by the splitter right. Now, after this there is a mirror on the mirror the ray will be reflected and it will pass through the flow field, there is a flow field.

So, it will pass through the flow field. After passing through the flow field again there is a splitter and here also there is a mirror. So, they will be reflected by the mirror and this is s2 and they will pass through s2 and there is a lens will pass through lens and then there is a screen and this lens is l2. So, this is the entire diagram or entire arrangement of interferometer that light ray is starting from here, they will move in this direction. Then part of the rays will go here, will pass through the splitter, part of the rays will be reflected. And then there is a mirror and there is a mirror here also this is m2 and this is m1. And the rays will be reflected, they will be passing through the flow field and after passing through so, field again they will go to this splitter, lens and then screen.

Now, suppose this the density is same in the entire system so, I mean ah there is no difference in the path travelled by 2 waves right. Suppose there is a change in density here, that will change that will create delta l, path travelled by the light by 2 by thirds or 2 roots. And delta l is equal to l n minus n1, that is change in the ah refractive index and delta l if you remember the equation that n is equal to 1 plus beta rho by rho s n1.

So, n minus n o is going to be equal to or we can take delta l as beta l rho minus rho o divided by rho s. That is a beta is already with us for different it is a constant it and it is a unique value for a particular fluid, For air I have already written the value of beta. l is known, l is the length of the flow field right rho minus rho o by rho s. So, this is the going to be the value of delta l and n is equal to number of fringes is equal to delta l upon lambda. So, this is also divided by lambda and this is also divided by lambda, this will give the number of fringes. So, this is how this technique can be used for flow visualization interferometer.

And the last one is LDA Laser Doppler Anemometer, it also adopts the same technique. First of all creating a path difference by virtue of density, change the dentistry in the flow field and then due to when the path differences is created, then the fringes will be developed right.

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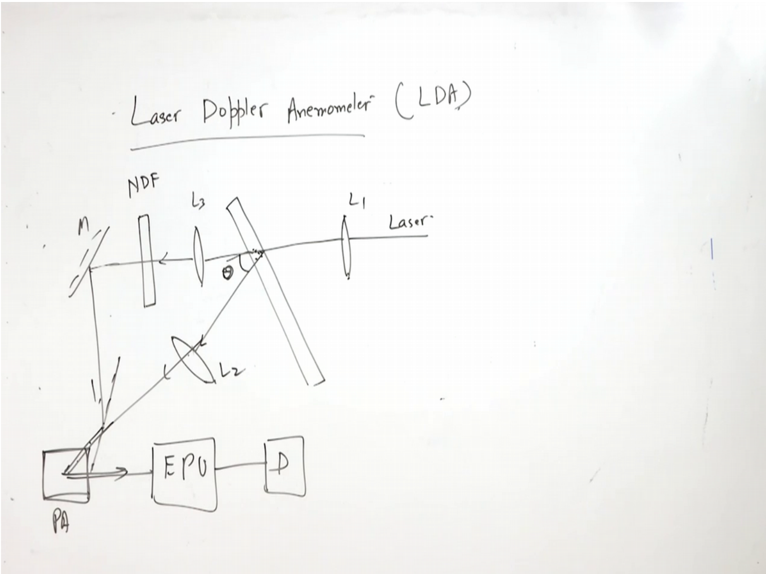


So, we will start with the LDA Laser Doppler Anemometer and it is also known LDA laser Doppler anemometer it is also known LDA.

In Laser Doppler Anemometer, as it is clear from the name it is a laser is used right. So, suppose there is a pipe, there is a flow in the pipe right and there is a transparent visual section in the pipe right and in transparent individual section a laser is short. So, there is a laser and laser will pass through the section right. Due to change in density part of the laser will be deflected in this direction theta, there is an angle theta, then there are lenses are everywhere in optical methods.

So, there is a lens here, this is this is l1 and there is a lens here, that is l2 and this is a lens l3. So, laser is coming from this side and after scattering from here. So, it should have some particles for all art, sometimes artificial particles are also injected to have the scattering right.

So, this deflection is due to scattering from the particles and suppose we take tap water, tap water has sufficient particles for ah for the purpose of scattering. So, we do not have to add some artificially some particles in the flow field, but sometimes they are required to be, if there are no particles for the scattering then the LDA type of system will not work.

So, laser will come to the pipe due to scattering the particles will be scattered at angle theta, to lenses there is a neutral density filter neutral density filter is there, then they will come to the mirror, there is a mirror. And from mirror then again there is a beam splitter, there is a mirror, from mirror it is coming to the beam splitter and from beam splitter and this beam will also come to the beam splitter.

Now, beam splitter will send these signals to the photo amplifier. There is a photo amplifier, photo amplifier the purpose of the photo amplifier is to enhance the signals right. When the signals are enhanced by photo amplifier then they go to the electronic processing unit and then display right.

This is the basic arrangement for ah LDA and LDA can have different type of arrangement; this is one of the arrangement. And the basic purpose is basic purpose is after scattering after scattering when this scattering takes place, these 2 rays they recombine and there is a photoelectric amplifier which amplifies the signals. And since there number of particles and there are number of particles right in the flow field. So, this theta will also keep on changing, it will not remain constant right.

So, and this is how we get the picture of entire flow field inside ah a tube. But, it is on the point to point basis, it is on the point to point basis. This is all for today for the flow visualization.

Thank you very much.