Experimental Methods in Fluid Mechanics
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Lecture 21
Laser Doppler Anemometry

Good afternoon, I welcome you to the session of Experimental Methods in Fluid Mechanics. And today, we will discuss about another Flow Measurement technique that is the instrument, rather the operational principle of the Laser Doppler Anemometry. In fact, this Laser Doppler Anemometry is an important noninvasive flow measurement technique and it is largely used to measure the flow velocity at a point.

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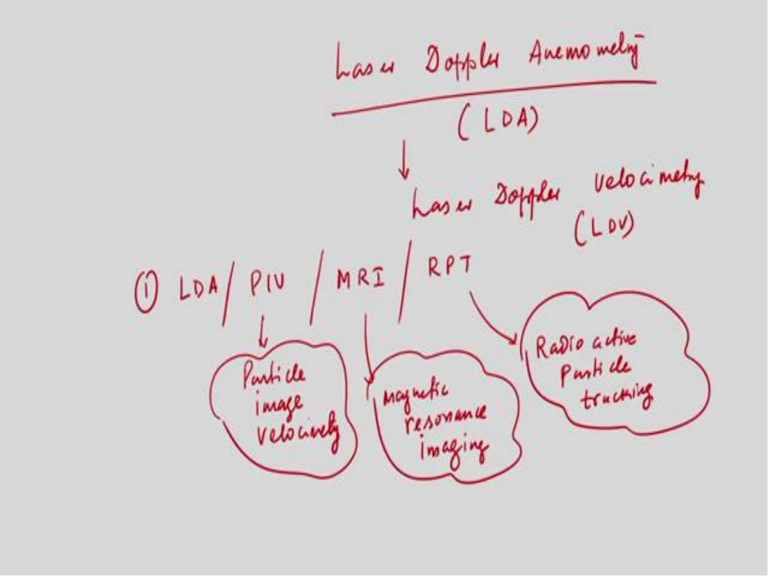

So, we will discuss today, this laser doppler anemometry. As I said that, laser doppler anemometry is an important noninvasive flow measurement technique which is used to measure, point flow, velocity at a point. Now, there are a few noninvasive techniques like so, this is LDA in short or sometimes it is also known as, Laser Doppler Velocimetry or LDV in short. Now, there are different other techniques which are noninvasive in nature and also used to measure the flow velocity, like I can say, LDA is one of them.

So, LDA, then we can have PIV, that we know that is Particle Image Velocimetry, then we have MRI, Magnetic Resonance Imaging, then we can have RPT. So, there are several other noninvasive measurement techniques available, which are used to measure velocity at a point. So, this is particle image velocimetry, this is magnetic resonance imaging, and this is radioactive particle tracking. So, these are the techniques which are used to measure flow velocity and which are noninvasive in nature. Now, question is why you are going to discuss about laser doppler anemometry.

Laser doppler anemometry relies on the measurement of velocity on the, you know, that are image based, in which we need to have a source of light. Now, the word itself is, or the word itself is sufficient to know that, in our laser doppler anemometry, the light source is laser. Now, as I said that laser doppler anemometry is a noninvasive technique, there are a few advantages featured.

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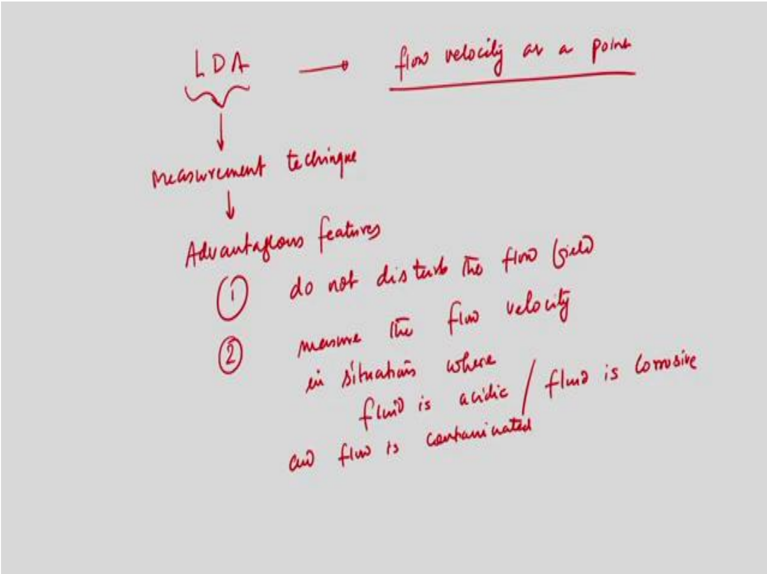

So, when you talk about LDA, this instrument, this measurement techniques. So, this measurement technique which is having a few advantages feature, so which is having a few advantages features. Now, number 1, do not disturb the flow field. We have discussed that, we can have measurement of flow parameters using probe, we can have measurement of volumetric flow rate using flow obstruction flow meter. In fact, we have seen in the last class that, we can measure velocity using hot wire or hot film.

In all these cases, we need to insert the instrument, we need to insert the object in the flow field. Now, when we insert the object in the flow field definitely that, you know placing or, you know in position of that particular instrument in the flow field will try to disturb. And as a result, we may not get the accurate actual velocity which you are going to, you know measure from using that instrument. So, from their perspective, this technique that is Laser Doppler anemometry is having advantage.

So, that is because, these technique do not disturb the flow field, and that is why the word noninvasive is came. Another important is that, this technique can be used to measure velocity in situations. So, it can be measured, this technique can be used to measure the flow velocity. So, when you talk about flow velocity, as I said this is used to have point flow measurement. So, this is used to measure velocity at a point. Now, measure the flow velocity, in situation where fluid is acidic, if the fluid is corrosive and flow is contaminated, with different foreign particles.

So, even again, if you would like to compare this technique with the other available techniques that we have discussed that hot film, hot wire, mechanical probe. In all these cases, we cannot, even if we use, I mean it will, the corrosive nature of the fluid, acidic nature of the fluid will try to, you know rather it will try to damage the measurement part, measurement points. If it is mechanical probe that will try to clog the point, clog the hole. If it is, you know hot wire, it will try to, you know tear the wire.

So, the presence of foreign particle and the different fluid properties like acidic, corrosive, these are not you know, I mean these properties are not important, rather we do not consider whether the fluid is acidic or corrosive or fluid is contaminated, while you are using LDA to measure the flow velocity.

So, these are the few advantages features which are associated with the LDA technique. Now, as I said that LDA that is laser Doppler anemometry and light source is the laser. Now, why we are using laser light, there are many other sources of light, instead we can use any radioactive also, radioactive wave, but we are using laser.

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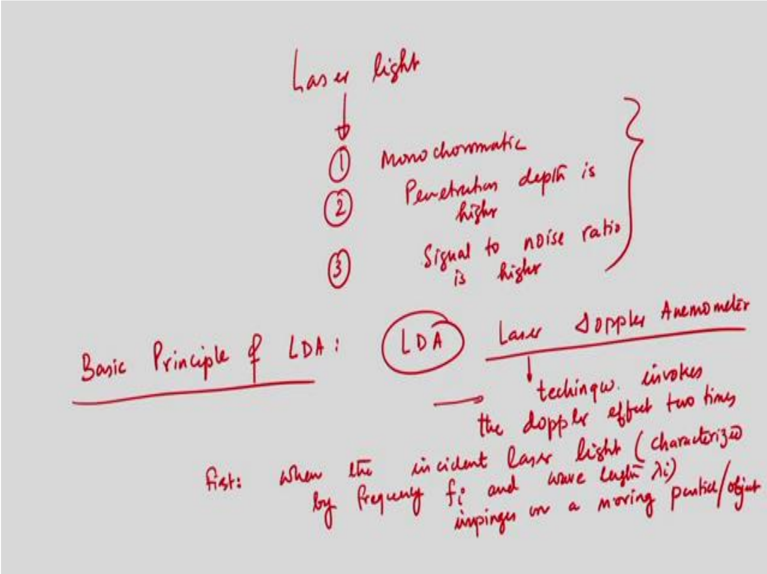

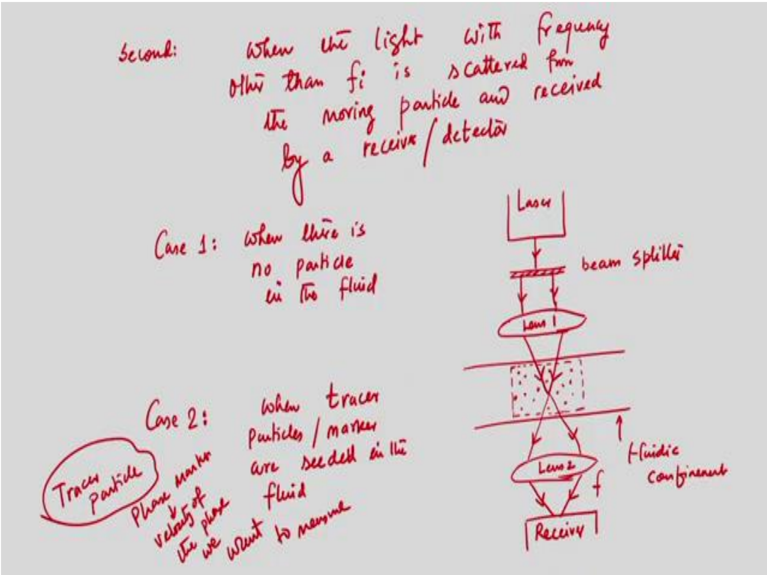

Because laser light is also having, laser light is also having a few important points, rather important favorable points that we should discuss now, that laser light is monochromatic, penetration depth is higher, number 3, signal to noise ratio is also higher. So, accounting all this 3, rather these important points we are using laser as a light source. Now, we need to know what is the basic principle of measuring flow velocity using the LDA technique or laser doppler anemometry. So, the basic principle that we need to know of LDA. So, now we will discuss the basic principle.

So, up to this time, we have understood laser doppler anemometry is used to measure point velocity, this measurement is noninvasive, this measurement is not disturbed, rather do not disturb the flow field.

And using this technique we can have flow measurement, rather velocity measurement of flow velocity when fluid is toxic, fluid is acidic, fluid is corrosive and if the flow is contaminated, so we need not to consider at all. If you try to measure flow velocity using another instrument like, mechanical flow or hot field, then these, you know kind of contaminated flow, corrosiveness of the fluid will try to destroy the lifetime of those instruments. But this is not an important points that we should consider, when we are measuring flow velocity using laser doppler anemometry.

Now, as I said that this technique uses laser as a light source and then light is incidented on a object and from there we, receive one frequency. So, when our light is incidented on object, so, we have a frequency and when the light is incidental of the object, that light will be scattered now, and from that object we also try to capture, received the frequency. Now, the basic principle is LDA is that, I am writing now that this LDA that is Laser Doppler Anemometer. The word doppler is there, so we will be using doppler effects. We have studied doppler effects in our class, 2 level, at 10 plus 2 level physics.

So, we have seen what is doppler effect and again today, we will discuss why this doppler effect is coming into picture, when we talk about flow velocity measurement using LDA. So LDA, a technique is that, that doppler effect this technique, this techniques, you know, invokes the doppler effect 2 times. First, first when the light, rather incident laser light, which is characterized by frequency fi and wavelength lambda i, when the incident laser light impinges on a moving particle or object.

So, the laser doppler anemometer technique, I can say this technique, this technique, doppler anemometry technique invokes the doppler effect 2 times. First, when the laser light, incident laser light which is characterized by the frequency fi, wavelength lambda i impinges on a moving particle.

And second, second is when the light with frequency other than fi is scattered from the moving particle and received by a receivers or detector. So, this is the basic principle, we incident laser light on a moving particle then, and we know the frequency and wavelength of the moving particle. And then second is, when the light is being scattered by the particle by the moving particle, the scattered light and the frequencies different then the fi and that frequency is received by a receiver or a detector. So, now, this is the basic principle.

So, now, we will take an example, we will see how we can really measure, rather we can use this technique to measure the flow velocity. And till now, we have discuss about the laser light frequency and we will see that we need we can corelate the measured frequency with the fluid velocity. So, I can show you that say, we have a laser source. So, this is a laser source and the laser light is taken into a splitter, say this is beam splitter and the light is divided to 2 parts and taken into a lens.

And then from lens, we can focus the light in a zone of our interest, say if it is of our, if it is the zone of our interest and we are focusing the laser light and the light which is, you know scattered is again taken into a lens and that is, you know collected by receiver, so this is receiver. So, this is lens 2, this is lens 1 and this is receiver. So, say we would like to measure the flow velocity and this is the confinement. So, this is fluidic confinement and we would like to measure the velocity of the fluid that is flowing through this confinement using this laser doppler anemometer technique.

So, what is done, there is a laser source, light is coming, light is taken to a beam splitter, essentially to split the light incoming light into 2 parts. The splitted now, lights are taken into a lens essentially to focus that light on a zone which is the zone of our interest. And then from there, we again, we the, you know scattered light is taken by into a lens and finally, the frequency or length or light or wave that is you know received by the receiver.

Now, see I can tell you, now when there is no any particle then the light is coming say, I can tell that there is no any particle. So, light is coming and the light will be received by the receiver. So, there will get one kind of frequency at the receiver, frequency of the receiving it. Now, say another condition where I am giving a few tracer particle here, this tracer particles and this tracer particles are seeded in the fluid and particles are neutrally wind, so the tracer particle. So, case 1, I can write now, case 1, when there is no particles in the fluid. And case 2, when tracer particles, sometimes they are known as marker, are seeded in the fluid.

So, marker means they are used to you know, mark the phases. So, phase marker, velocity of the phase we want to measure. So, basically the tracer particle, tracer particle also known as phase marker, you know, that is, you know, velocity of the phase we want to measure. So, now tracer particles, when here, when the tracer particles are seeded in the fluid.

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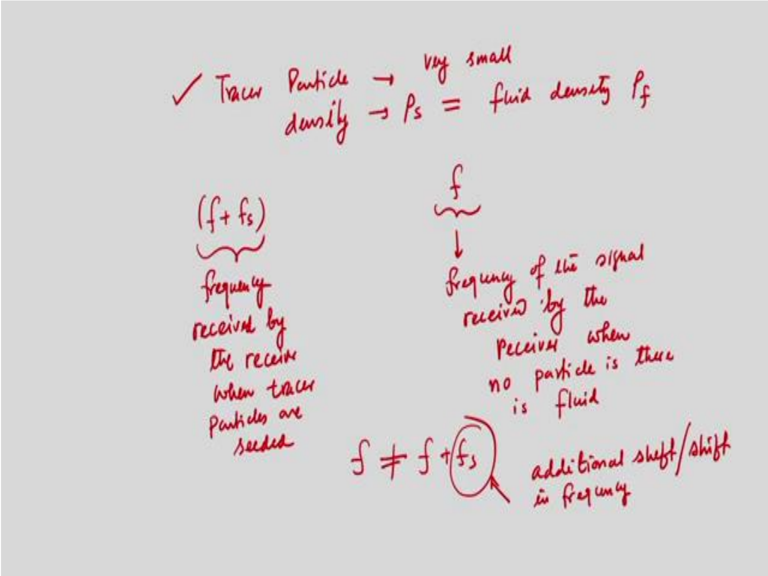

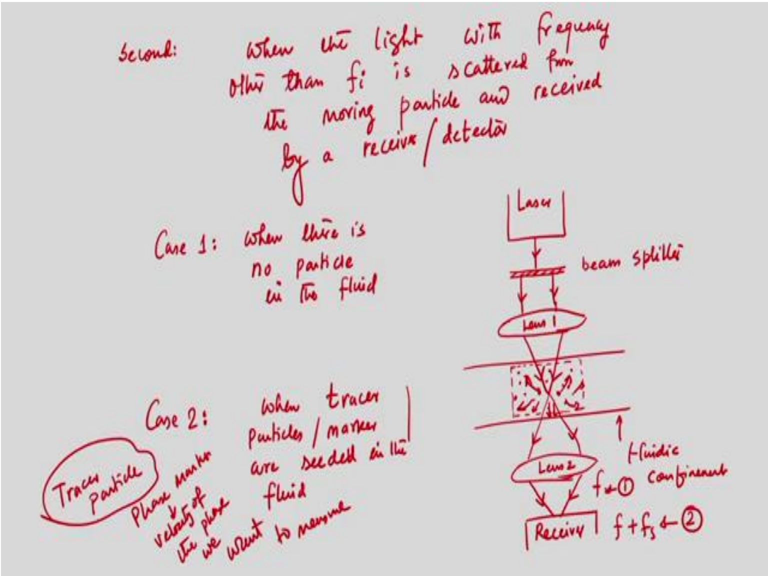

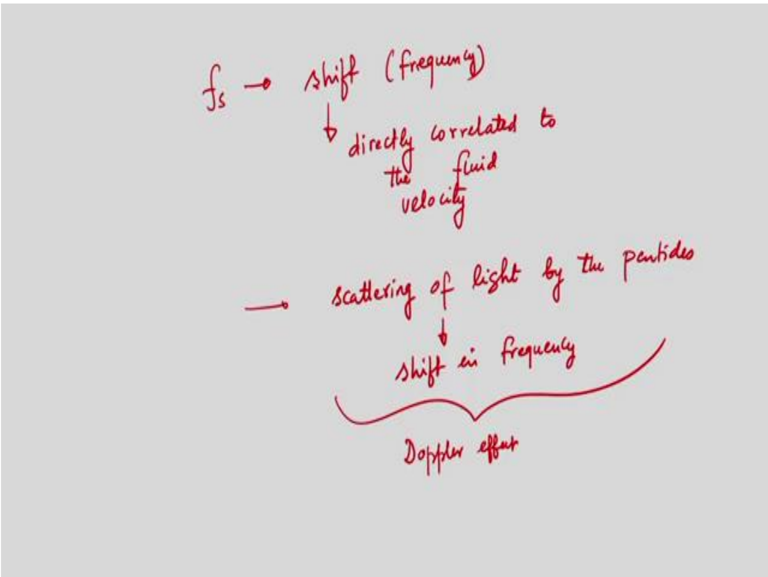

Now, the important characteristics of the tracer particular will be the density of the particle. So, the tracer particle, I am writing the tracer particle density is row s and this is equal to the fluid density, row f and tracer particles are very small. So, tracer particles which are seeded they are very small and density of the particle is equal to the density of the fluid, so that they can follow the flow. Now, that is they are neutrally buoyant. So, the particles which are seeded they will largely follow the flow direction and density is equal.

So, these 2 are the important, I know, I can say points we need to consider when we are you know seeding a tracer particle to essentially to measure the flow velocity. Now, if I go back to a previous slide, I can tell when there is no particle of course, the receiver will receive signal, the light which is falling on the object from the laser source and receiver will definitely receive a signal. In that case, if the signal frequency is f and the second case when we seeded up few particles and the particles when they are seeded, now when the light is, you know incidenting on the particle, they will try to transmit, transmit in different direction.

Now, there will be transmission directions which are in the direction of the receiver. So, when the particles are seeded in the fluid and particles are neutrally buoyant, they will follow the fluid motion, when the light is now falling, light falling on the particles, there will be a, you know scattering of the light by the particle in different direction, there will be direction of the scattered light, which is in the direction of the receiver. Say, in that case the signal received by the, this is for the 1, case 1 and in that case, f plus fs and say this is for the case of 2 that is when a fluid is having a few seeded particle.

Now, obviously, this f plus fs, so f plus fs, so this is the frequency received by the receiver when tracer particles are seeded, while f is the frequency of the signal or light received by the receiver when no particles, no particle is there in the fluid

That means, therefore, this f will not be equal to f plus fs and this fs is a shifting frequency. This f plus fs may higher than f, may lesser then f, that will depend upon so many things that we will discuss now. But what we can say that the frequency received by the receiver in absence of tracer particle, will not be equal to the frequency received by the receiver in presence of the tracer particle. And this fs, is nothing but the phase shift and this fs is known as frequency shift or additional shift or shift in frequency.

Now, this shifting frequency can be directly correlated, this fs shift, frequency shift of course, this shift can be directly correlated to the fluid velocity and that is what we will now discuss.

So, that means, what we are using, we are using scattering of light by particle, for which we have a shifting frequency. So, that is the doppler effect and that is how doppler effect is coming into picture, when we talk laser doppler anemometry. So, that means scattering of light by the particles, scattering of lights by the particles and as a result of which phase shift or shift in the frequency I can say, shift in frequency and this is the doppler effect.

So, that is how doppler effect is coming into picture, because what we are doing? We are using the scattering of light by the particle which are seeded in the fluid. And from there we are trying to measure the shifting frequency and from that shifting frequency can be directly correlated to the fluid velocity. Mind it, the particles which are seeded in the fluid are the, are neutrally buoyant, the density of the particle is the density of the fluid. So, the particles are expected that the particle will largely follow the flow direction. And from there, we can correlate the fluid velocity.

So, next we will see how we can now calculate the, you know, that shift and that shift can be correlated with fluid velocity.

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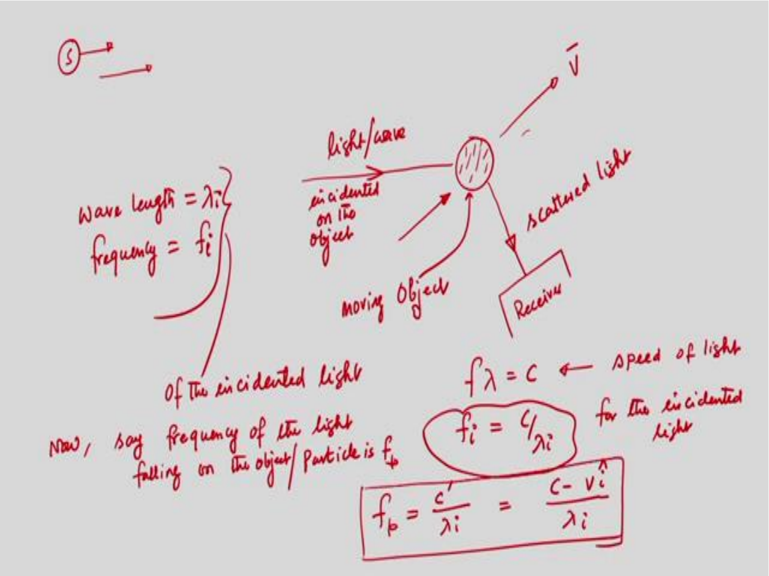

So, if we consider there is a object and our light or wave is incidented on that object. So, this is the object and that object say is moving in this direction, with a velocity v. So, the object is moving. So, this is the object, which is moving and light is incidented on the object. So, say the light is falling on the object, object is moving v. So, the light will, the object will try to scatter the light and the light scattered lights that is say received by the receiver. So, this is the receiver.

So, this is scattered light. And this is the moving object, and this is light or wave incidented on the object. And if we considered the wave length is lambda i, and frequency is fi of the incidented light. So, object is moving in the, with the velocity v and light is falling on it having frequency fi and lambda i and there will be scattering and a scattered light is received by receiver. Now, we know that f into lambda is nothing but c that is the speed of the light. Therefore, fi will be equal to c by lambda i, for this particular case, for the incidented light, that we can write.

So, fi is equal to c by lambda, so the, this is what the frequency of the incidented light. Now, particle is moving with a velocity v, so the frequency of the light which is falling on the particles that we need to calculate. So, if we try to calculate, I can write over here. Now, say frequency of the light falling on the object is fp, say this is fp on the object of particle, so on the particle or particle fp. Then, this fp will be, it should not be c by lambda I, it should be c dash by lambda i. Because particle is now moving, it is not stationary.

So, the light which is falling on the particle, the light has frequency fi that is c by lambda i that is what we know, we have assumed the frequency of the light is fi. Now, the frequency of the light, the frequency received by the receiver in presence of particle. So, the receiver will now receive a frequency and that is fp and that is c dash by lambda i. So, if the particle is not there, then the receiver will receive the frequency that is equal to the fi. But now, because of the presence of the particle which is moving with a velocity v, the receiver will now receive a signal that is fp that is c by lambda i.

Now, that is nothing but, I can write c minus v by lambda i. And, I would like to put an unit vector i over here, because, the particle moment if it is in the direction of light, incoming light and particle both, you know the direction of both the light and incoming light and particles are in the same, then the unit vector will be minus 1. But unit vector will be 1, but if they are in the opposite direction, so the, if the particle moves in the direction from where the light is coming, then the unit vector will the minus 1 and that will be c plus vi.

So, we can assume as if someone is creating a sound, say someone is creating a sound from this source, so this is source, he is creating a sound and sound wave is coming in this direction and someone is also moving from, you know away from the source and with time what he or she will face that with time the, you know sound waves will be reduced. So, that means, the source and the object, both of them are moving in the same direction. So, that I mean, source is not moving, the you know light which is coming from the source, the direction of the light and the movement of the object in the same direction.

So, with time the, you know strength of the frequency will reduce and that is the c minus vi. Now, if they are in the opposite direction that means, if the light is coming from a source and object is also moving towards a source then that will be c plus vi. So that means, the strength or the frequency will, you know keep on increasing. So, now, this is c minus vi by lambda, so that we can write.

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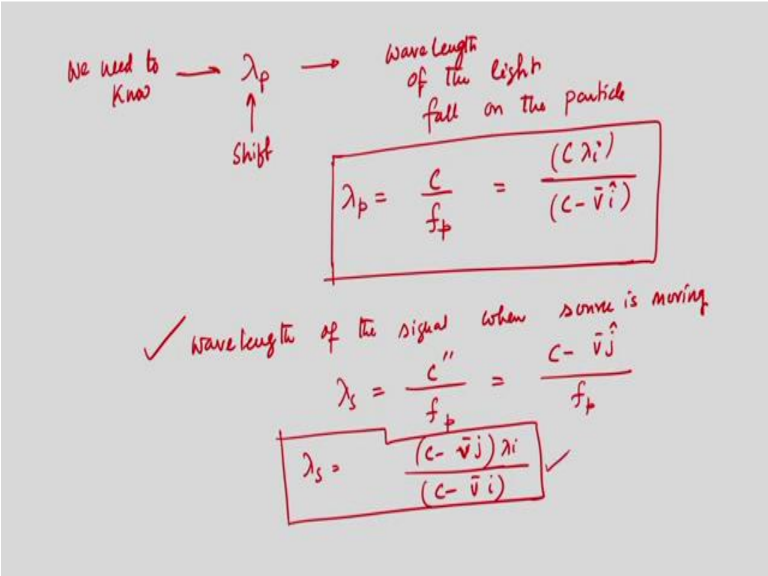

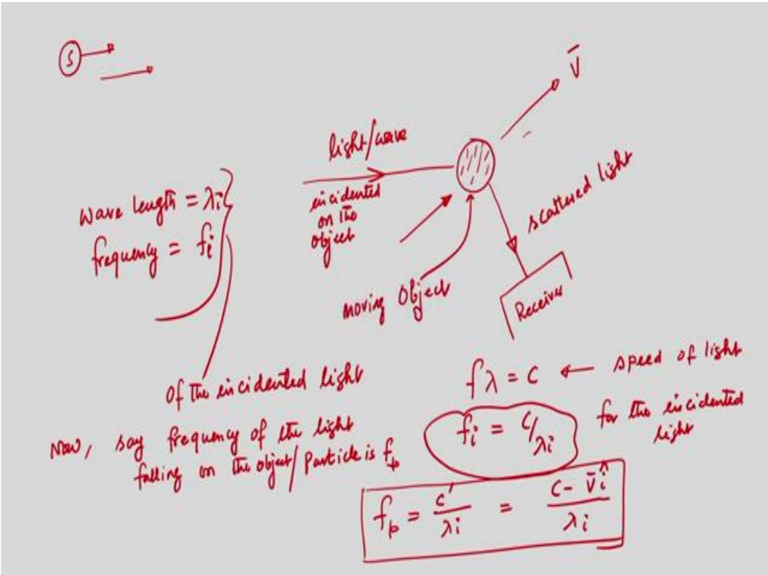

So, when you know the frequency fp, then we will like to calculate lambda p. So, this lambda p essentially the first shift, this is the shift. So, lambda p is the frequency, wavelength, lambda p is wavelength we need to know, we need to know lambda p, lambda p. And that is wavelength of the light, you know fall on the particle, the frequency of the light. So, lambda p will be equal to, you know c by fp using that relationship. Now, if I plug in the value of c by fp that is, c into lambda i divide by, you know c minus v into unit vector. So, this v is vector. So, this is v and so, this will be unit vector. So, this is lambda p.

Now, so that means, now object a light is falling on the object, object will try to scatter, object is moving in the direction, you know with a velocity v. So, we will get a frequency and that is what we have calculated and we have calculated wavelength. Now, if the frequency of the incident light, rather if the source is moving, so now, we need to receive a signal by the receiver when, as if the object is moving. Now, the light that will be transmitted by the, you know kind of I can say, so this is lambda p.

Now, the particle is moving with the fluid. So, the particle velocity is equal to the fluid velocity, light is falling on it, it will scatter light and we have calculated wavelength of the light fall on the particle lambda p.

Now, the light is now moving, the object is now moving, as if now we will received the, a signal from the object by the receiver. So, now object is moving as if the source is moving, in that case what will happen. So, if, the wavelength of the signal when source is moving. So, now question is as if the light is, you know incidented on the particle, particle will scattered and we have calculated the frequency, the wavelength of light fall on the particle lambda p that is c by fp. If there is no particle, the receiver will receive fi that is lambda.

Now, the wavelength which is falling on the particle is lambda p, but wavelength that will be received by the receiver when particle is present that is lambda s and that is again, c double prime, say c double prime by fp. This c double prime again it is c minus vj, I again do not know where, because again I am using the unit vector j. And again, we can apply the same argument if the, if the direction are in the same direction, if they are in the same direction, j will be plus 1.

If they are of, you know approaching towards them, then it will be minus 1. So, c minus vj by fp. And if I put the value of fp from the previous equation, then lambda s will be equal to, rather I can write c minus vj lambda i by c minus vi.

So, this is the expression of the lambda s, when source is moving. Again, I am telling when there is no particle, receiver will receive a signal that frequencies of high, when the particle is there, because of the moment of the particle, the wavelength which is falling on the light, on the particle that will be lambda p that you have calculated. Now, again wavelength it, the particular is scatter a light. The frequency of the light that is being kept, frequency, rather of the signal or light that is being received by the receiver will be lambda s and that is c double prime by fp and that is nothing but c minus vj by fp and we have calculated this.

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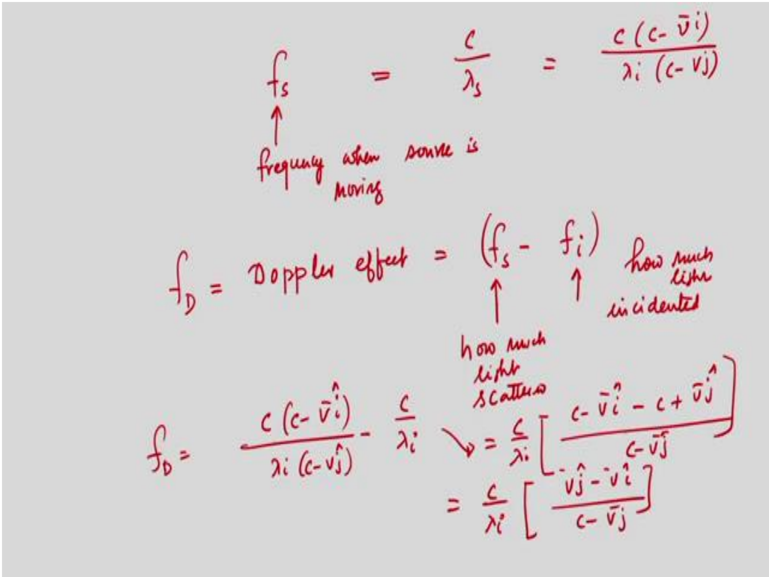

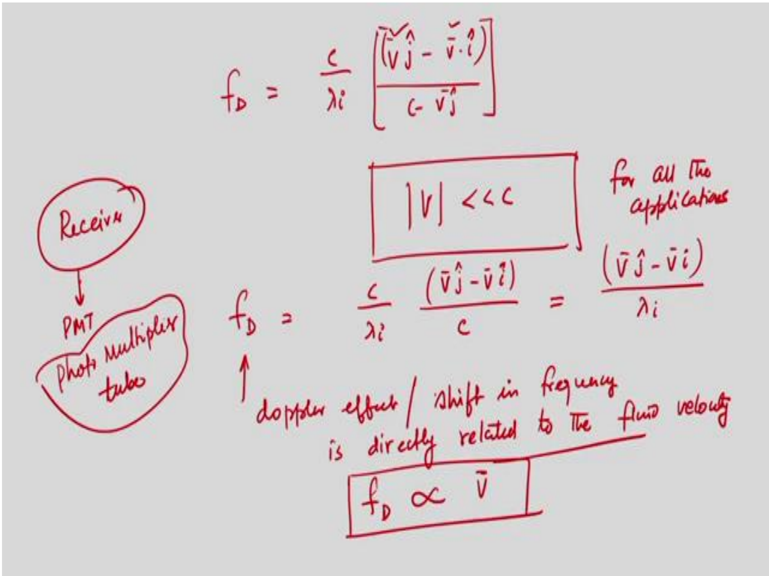

So, I can say, what will be now fs, so what is fs. So, frequency when source is moving. So, that will be equal to c by lambda s and that is nothing but c into c minus vi divide by lambda i into c minus vj. So, what is a shift in frequency, that is very important. Now fD, that is the doppler effect. So, fD that is the doppler effect equal to fs minus fi. So, the light, the amount of light, how much incidented on the object? How much being scattered by the object? So, this is the, you know, incidented and this is how much light scattered. And, this fD if you do algebraic manipulation, we can write.

This is nothing but, c into c minus vi divide by lambda i into c minus vj minus fi is equal to c by lambda i. So, if I take now, c by lambda i out, then we can write c minus vi minus c plus vj these are the unit vectors by, c minus vj. So, this is c by lambda i into vj minus vi, by c minus vj.

So, ultimately, we can write fD that is doppler shift, is vj minus vi c by lambda i by c minus vj. So, you can see the doppler's, that is you have written over here the doppler effect. Now, the change in frequency can be directly correlated, that is fs that is what we have, you know discussed at the beginning of this class, that doppler effect, the shift in frequency that can be correlated with the fluid velocity.

Now, in most of the applications, the you know most of the application I can say, almost for all the applicants, if I write that light intensity of the laser, I mean v the velocity of the fluid is much ,much less than c that is true for almost all the applications, for all the applications.

If that is the case, then fD is equal to, I can write c by lambda i vj minus vi divide by c. So, this is equal to v into j minus v into i divide by lambda i. So, we can see that the doppler shift that is what we told at the, rather in the beginning of this course, this doppler shift, doppler effect. Shift in frequency, shift in frequency is directly related to the fluid velocity. So that means, fD is proportional to v function velocity. So, what we can say, that means, we have discussed light is incidented on object, if there is, there is no particle, the signal received by the receiver will be fi.

In presence of particle, which are tracer particle which are neutrally buoyant, density is equal to the fluid density that means, the particles are following the, you know bulk flow. Now, in that case, if the light is incidented on the particle, the light will be scattered by the particle. In that case, we have calculated the frequency of the light which is falling in the particle. And, now source is moving, in that case the signal received by the receiver again we have calculated by fs.

So, now, fs minus fi, that is nothing but the doppler effect that we have calculated, and we have seen that the doppler effect that is shift in frequency that can be, you know captured by the receiver, receiver is nothing but, you know photomultiplier tube. So, this receiver we have, you know shown in the schematic, the receiver is essentially photomultiplier tube. So, when light is received by this photomultiplier, the photo it absorbed photo energy and that energy is getting converted to the current and from there we can calculate the frequency. So, this photomultiplier tube, photo multiplier tube.

So, this is the receiver. So, it receives photon, that energy is converted to the current and from there we calculate frequency. So, now by calculating the frequency from the receiver, we can directly correlate to what will be the velocity of the fluid.

So, this is what is the basic principle of the LDA technique, the mathematical analysis that we have done, that is not particular. This is a genetic analysis, this is valid almost for all the light (())(46:27) based technique. Now, to summarize what we have discussed today, that is very important that I can write for the sake of completeness, that principle.

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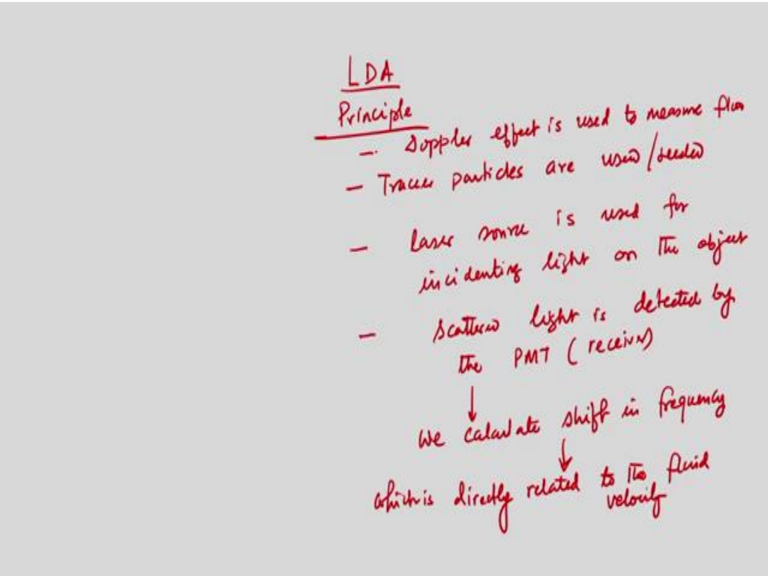

So, LDA, the principle that is tracer particle, tracer particles are used or seeded, doppler effect is used to measure flow, flow velocity measurement that is point velocity measurement. Laser source is used for incidenting light on the object. Scattered light is detected by the PMT or receiver photo multiplier tube and we calculate shift in frequency, and this shift in frequency is, which is directly related to the fluid velocity. So, this is the basic principle of using laser doppler anemometer to measure the flow velocity that is the point velocity.

We have discussed that flow measurement is the volumetric flow measurement, point velocity measurement and the determination of the flow streamlines. We have discuss about the techniques which are used to measure volumetric flow rate, we have discuss about the techniques which is used to measure point velocity that is hot wire and hot film and today we have discuss about LDA. And today we have discuss, about the basic principle by which we can measure flow velocity and we have seen this is completely a noninvasive technique and which is used in situation where fluid is corrosive, acidic and flow is highly contaminated.

And since, this is not immersed or this is not placed in the flow field, they do not disturb the flow field and as a result, the measurement which we are obtaining using this technique is almost accurate one. So, today, we have discussed about another important technique, which is used to measure the velocity at a point.

And we have discuss, about the basic principles with small, you know mathematical analysis that, how you can calculate the flow velocity, rather how you can calculate velocity in with the frequency of the light which is falling on the object. So, with this I stop my discussion today and we will continue my discussion next class. Thank you.