Measurement Technique in Multiphase Flows

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Lecture – 05
Laser Doppler Anemometry

So, welcome back. Now what we are going to start today is about the non-invasive velocity measurement techniques. So, till now we have already discussed about the invasive measurement technique. And in invasive measurement we have discussed about the pitot tube, we have discussed about the hot wire anemometer, we have discussed about the optical fiber probes. And whatever we have tried to learn that, though some of the technique like optical fiber probe and hot wire anemometry, you reduce the size of the probe. But the invasive nature is still be there.

And because of that, the measurement can change. Or the flow dynamics it can change at the point of measurement itself. And therefore, there is a need if you want a better accuracy. You there is a need to develop a non-invasive technique. Further, that as we have discussed, that in hot wire anemometer, as well as in optical fiber probes, that the probe which were inserting inside, cannot sustain a medium which is very corrosive, or signed off say the medium conditions are very, very harsh. Say, very high pressure, very high temperature. Then the life of the probe will reduce, and that will actually enhance the price of your measurement.

And therefore, the non-destructive technique, or non-invasive technique has been used which does not actually interfere with the flow. And so, therefore, you can use these techniques in a very adverse environment. Say, very corrosive flow, a very high temperature flow a flow which is highly contaminated. So, all these flow or flow where the scaling can be there. So, all these flows you can use this non-invasive measurement technique, and that gives the major boost to the measurement technique as per say, that you can do the measurement without disturbing the flow, and that too for a very harsh flow conditions.

So, that is the major advantage of non-invasive technique, and as I said that there are several class of the non-invasive technique there are different non-invasive techniques available to measure the velocity, we are going to discuss in this part some of them, and those are mainly laser Doppler anemometry metry it is also called velocimetry, or we will call an LDA.

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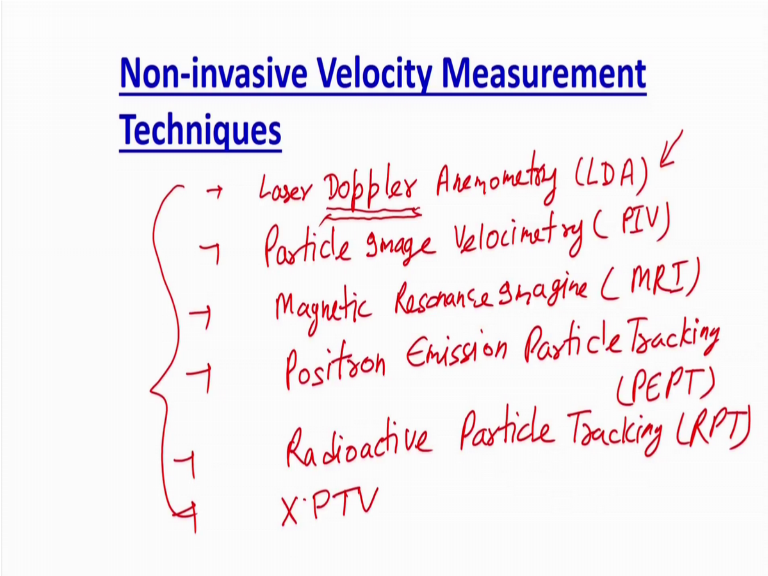

We will discuss about the particle image velocimetry, image velocimetry, we called PIV, then we will discuss about magnetic resonance imaging; that is called MRI, then we will also discuss positron emission particle tracking, we call it PEPT, we will discuss about radioactive particle tracking called it RPT. And we will say that x ray xptz x ray particle tracking velocimetry. So, x p x. So, all these techniques, we will try to discuss x ray particle tracking velocimetry.

That is why xp tv, we will discuss about all. Now the major advantage of all these techniques is that they can be used they do not disturb the flow, they can be used for the harsh flow conditions, harsh flow conditions what I am talking about the chemical property of the this flow, say if very highly acidic medium is there, highly corrosive medium means there, highly contaminating medium is there, you can still use these flows. But each have their own limitation their own advantage, their own working principle, and that is what we are going to see here now.

So, what we will do, we will first start with a very basic technique was kind of one of those initially developed non-invasive technique of the old non-invasive technique; that is, laser Doppler anemometry. So, let us try to understand that, what is laser Doppler anemometry. Now definitely one term which all of you might we have heard, definitely that is called Doppler. So, you might have heard about the Doppler effect in your undergraduate courses. And even in your plus 2 level courses. We will try to revise some of the fundamentals, and how the Doppler effects is actually being used to measure the velocity. So, what we are going to do? In the laser Doppler anemometry, we are going to use the Doppler effect to measure the velocity field.

Now, how we are using it? What is Doppler effect? We all kind of try to understand all this. So, as I said what is laser Doppler anemometry.

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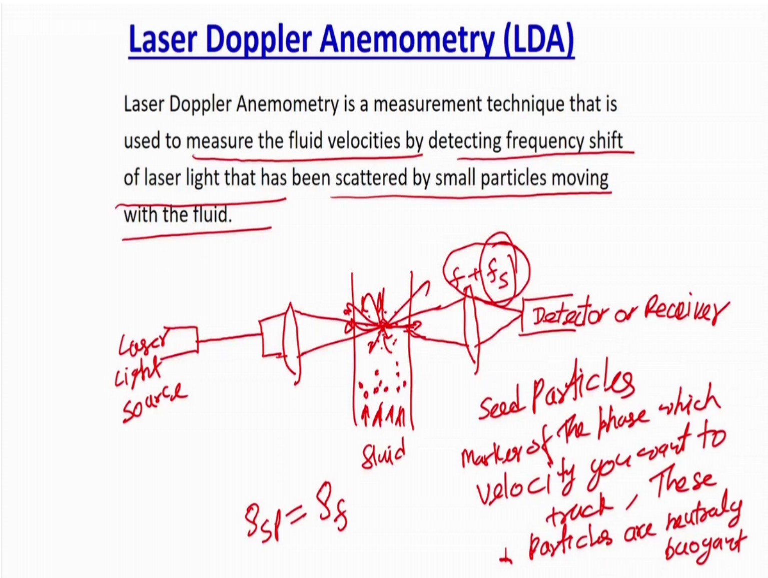

Laser Doppler anemometry is a measurement technique that is used to measure the fluid velocity by detecting frequency shift of a laser light that has been scattered by small particles moving with the fluid. So, that this technique actually uses the scattering of the because of the lights moving particles. And that is the reason that why the Doppler effect comes into the picture.

So, it means what? If suppose we have a light system, where we are incidenting the light at a certain place, without kind of scattering it, without having any particle inside in a certain medium. Then we will receive some signal on our detector. Suppose, if I am using a receiver, I am incidenting laser light or a light on a particular medium, I will receive some of the signal. Now if I will flood that medium, or if I will introduce some neutrally buoyant particles; which are moving at a certain velocity in that medium, then what will happen these particles will be scatter the lights, and now the signal received on the receiver will be less or higher, than the signal received initially without the particle presents. So, what we can do? We can correlate the shift in the signal by velocity of the fluid, because we have introduces, we have introduced some of the neutrally buoyant particles. It means they are going to follow the path of the particles part of the fluid.

So, we can calculate the shift in the frequency with the velocity of this moving object of moving particle. And that is the basic principle of laser Doppler anemometry. Now the flight which has been incidented on this or the waves which has been incidented in the medium is a laser source, and that is why we call it as a laser Doppler anemometry.

So, we are going to do the Doppler shift, and what we do we do a very simple thing; say, we have a laser light source. So, this is laser source, we are incidenting a laser; say, this is the laser and let us assume that we are breaking the laser in these 2 parts, we are incidenting it on a particular z1 by using a lens, and this is say my measurement volume or measure the flow area where we are measuring, and then again, we are collecting the signal and focusing it on a detector. So, this is my detector or receiver.

So, what will happen? Suppose there is a fluid which is flowing inside; which is fluid, which is flowing inside. Once this laser light will fall what will happen this detector or receiver will in it is kind receive certain intensities. Now that intensity how much it will receive that will depend on the intensity of our frequency of this laser light and medium density. So, that we know already. So, we will come to a detailed mathematics later on. So, that will it will receive some of the signal.

Now, if I introduce some of the neutrally buoyant particle in it, then what will happen? This particle once they will go, it will actually do some frequency change. Now they will scatter the light. Now once they will scatter the light they will scatter it in all the direction, and some of the scattering will also fall in this direction, in the direction where the receiver is there. So, what will happen? Say initially the frequency was something. Now you will get the frequency which is scattered also, this frequency. And there will be a shift in the frequency now the receiver will see that, the frequency has increased.

Our frequency has decreased that will depend on the velocity of the object velocity of this particle and the direction of this particle velocity. So, this shift in the frequency, this shift additional shift at the frequency is directly correlated to the velocity of the moving object, and that correlation can be established by using the Doppler Effect. And that is why the Doppler effect actually is being used to measure the velocity of the flow fluid a flowing fluid in the LDA. So, that is the whole principle of the LDA.

Now, we will discuss about the Doppler shift and other did mathematics of the reconstruction in detail, and the equipment used. But that the basic principle is you are actually introducing some seed particles, we call it seed particles, which are nothing but a neutrally buoyant particle. So, these are seed particles. And these size seed particles are nothing but the marker of the phase; phase, which velocity you want to track. And these particles are neutrally buoyant. It means the density of the seed particle SP is equal to the density of the fluid. So, they are neutrally buoyant. So, they will follow the path of the fluid.

So, the velocity of these neutrally buoyant seed particles can be correlated, or can be said that if the particles are very, very small they are following the path of the fluid their velocity and the fluid velocity will be equal. And the velocity of these particles can be directly correlated with the Doppler shift in the frequency observed at a receiver. So, that is the basic principle of the laser of the laser Doppler anemometry.

So now, what we do in the Doppler shift or what it how it happens; so, let us assumes that a wave is being incidented.

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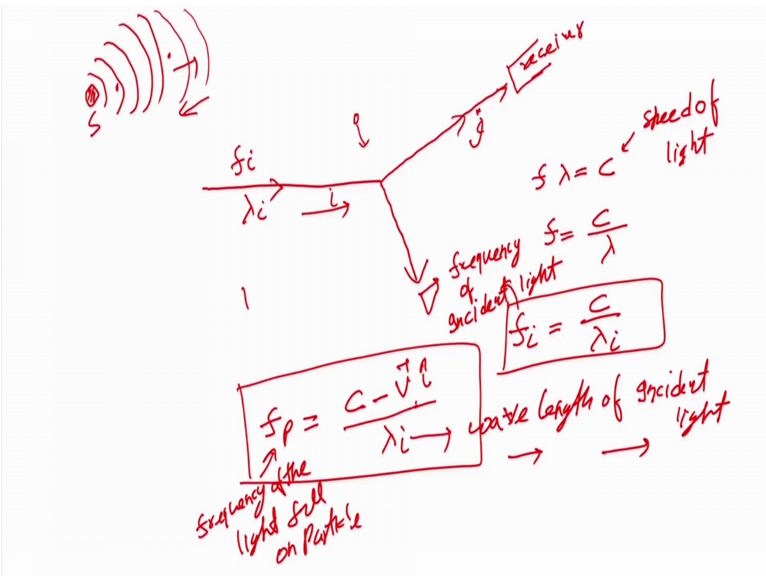

Now this can be a wave, this can be a light, this can be a ultra-sounded waves anything, or radio waves anything, all will follow the Doppler shift. So, what we are doing? We are using the laser light, why the laser light their monochromatic lights, their penetration and submitter. So, the signal to noise ratio is much better in case of the laser compared to the ultrasound or radio waves. And that is the region that the laser is being used to measure the velocity. But in principle whatever the mathematics we will do, you can use the same mathematics for the radio waves, you can use the same mathematics for ultra sound waves or any sound waves.

So, you can use the same mathematics here. So, what we are going to do? We are saying that suppose, there is a which is being falling here at this place, at a certain frequency and certain wavelength. So, say the wavelength of incidenting is lambda i, and the frequency is fi. So, why I am using i. i means incidenting waves or incidenting light. Now suppose there is a receiver which will being there is some the particles are there, and because of that some scattering take place. And the receiver is actually on this side. So, say this is my receiver, this is my receiver.

It is scattered, once it is scattering it will go in all the direction. So, this is some scattered light it is going on. And there is some velocity which is coming here. So, this is the velocity of the object. So, object which is moving in this direction, and this is the velocity v of the object, in this direction the receiver is being scatter and that is scattering actually, the light or the wave which is being incidented on this particle, and that is going it in this direction receiver direction.

So, how the Doppler shift will work? So, we know that if suppose, this is a light, then we know that the formula the correlation between the f frequency and wavelength. And that is what f into lambda is equal to c; where c is speed of light. So, it means you can say f is equal to nothing but c upon lambda, this we have already done. Just I am trying to revise it. So, this you have already done that it will be f is equal to nothing but c upon lambda. That whatever the frequency will be there. Now that is the frequency if suppose I am talking about the incident waves, that will be our incident light it will be c upon lambda i.

So, that part is clear, now what is there? This will be the incident, which will be the receiver will receive, incident life through vacancy, which is the receiver will receive if there is no particle. Now if suppose there is a particle which is moving with a velocity v.

The way we have defined the particle which is moving with a velocity v, then what will happen? How much of the intensity chain? What will be the frequency now you will see? Or the change in the frequency you will see on the receiver. That will depend that what is the velocity of the c particle? So, we can write it that, if suppose there is a particle, in presence of the particle, what will be the frequency which you will see on the receiver?

So, that we can write it as fp, and fp is nothing but c minus v into upon lambda. Now this can be minus, this can be plus, if it will be minus, if the velocity is in the direction of the velocity of the source where the incident it is incidented. Means, if the velocity is in this direction, the direction at which the light has been incident, this will be minus. If the it is the opposite direction, that this will be the plus, and that is why I am introducing a unit vector i, which value is 1, if it is parallel to the incident direction is minus 1, if it is opposite to the incident direction.

So, once it is parallel, what will happen? You will see the waves which will become. So, this is the say incident waves is coming it in this direction, you are moving it in this direction, then you will see the lesser frequency the frequency will be reduced. So, suppose someone is blowing horn someone is driving a motorcycle and he is blowing horn and if suppose you are also moving, let us assume and you are moving far from them. It means you both are moving in the same direction. So, you are moving far from him, then you will see the less frequency. So, what will happen? That the frequency will actually reduce.

So, let us see this. So, let us assume that someone is blowing a horn. And let us assume you are moving, source is not moving. So, this is source, this is you. And you are moving it in this direction. Someone is blow horn, what you will happen you will see certain frequency? In this way, you will see certain thing. Now if you are moving far, what we will see? You will this frequency will be reduced, this will be shift that will be more divergent will take please. So, this will be actually intensity of this frequency will reduce. And what you will see will not see the original intensity which you are seeing if you are somewhere here. So, at this place you will see the lesser intensity.

So, if you are moving at a velocity which is the similar direction to the velocity at which the waves are being introduced, you will see reduce in frequency. And that is why cc minus v, and the value of i in this case will be plus 1. But assume that you are moving in the opposite direction, then what will happen? Now with the time, you will see more intensity, the intensity of the sound will increase. So, the value of i if you are moving, opposite to the direction at which where the waves are being propagated, you will see the positive shift in the frequency, you will see the increase in the frequency. And that is why this value will be plus, and therefore, the value of i will be equal to minus 1.

So, I hope this is clear, that what you will see in case of this, and this will be the lambda i. So, fi is the frequency of incident light, incident in light. The frequency of particle this is been particle, this frequency or the light; which has been fall on the particle, fall on particle. Lambda i is the wavelength of incidenting light. So, this is the way, the fp will be given. Now what we need? We also need to find that what will be the lambda p. Lambda p means, what is the wavelength of the particle, particle frequency so, the light which has been transferred on the particle, what will be the frequency of that light?

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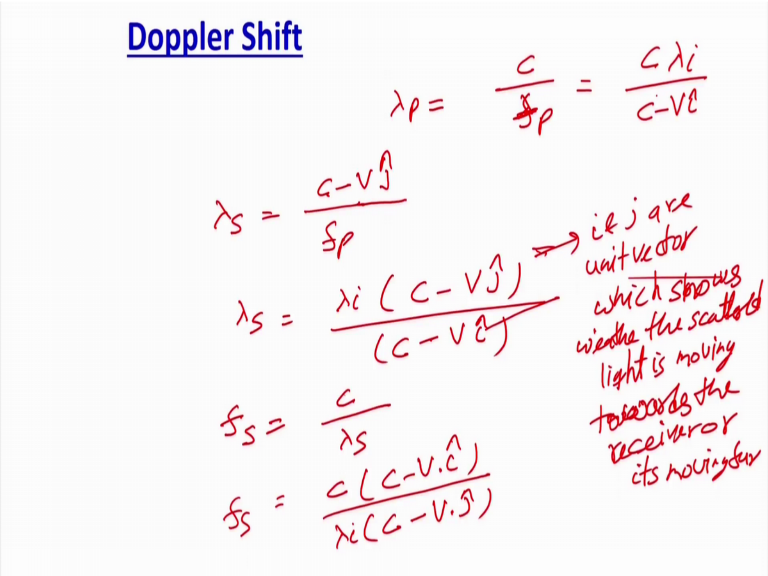

So, we can say that this lambda p that is actually about the Doppler shift, that the lambda p is equal to c upon f of p. That will be the lambda p. So, it is same thing what I have written f p is equal to c upon lambda p. So, lambda p equal to c upon f p. Now fp value we have already calculated that is c minus vi upon lambda i.

So, you can write it as c into lambda i upon c minus v into i. i is a unit vector. So, that is this will be the lambda p. That will be the lambda p. Now if I assume that, the source is also moving. If the source is also moving towards the, this, then what will happen? You will see a certain velocity again. And that the frequency of the incident light where the source itself is moving will change. And let us assume that is nothing but lambda s. So, lambda s will be what? It will be equal to c upon fp. And this c will not be the velocity of the light, but it will be c minus velocity of this of the object in the direction of the source.

So, say let us assume that that is j. So, if it is parallel to the source direction, it will be negative again, if it will be opposite, then it will be positive clear? So now, we have done that lambda s will be equal to what c minus v of j upon fp. Now fp we can replace again from the value which we have calculated. So, we can say that lambda s sorry fp is nothing but c minus vi upon lambda s. So, lambda s will be equal to lambda i c minus v into j upon that is lambda sorry this is f p c minus into c minus v into I, which i and j are the unit vectors. i and j are unit vectors; which shows the direction. Vector which shows whether the scattered light, light is moving towards the receiver or it is moving far far.

So, that is what is the i and j are the unit. These things, now what you have done, we have calculated the lambda s; the wavelength of the, how that the source will be there. Now what we are going to do? We are say that, we are going to say that where the scattered light has moved the wavelength of that scattered light we have already calculated. So now, what we can do? We can calculate the value of fs, and fs will be nothing but, it will be again c upon lambda s. So, fs will be nothing but c upon lambda s. And lambda s can be written as c upon, this will be c minus v into i upon c minus g into j. And that is multiplied by lambda i.

So, that is the way fs will be given. So, fs we can write it in form of this, and this is fs. And earlier whatever we have said that, whatever the lights which will be incidented here, that fp we have already calculated, and the incident of the light f i, we have already calculated. So, fi we have already calculated, fp we have already calculated, and now we have calculated that the frequency of the scattered light. The direction it will being is scattered. So, this is the i direction, j direction, sorry the scattered light. This is the I direction. So, we have already calculated that the scattered light frequency, now what we need to do fD is nothing but this will be equal to fs minus fi.

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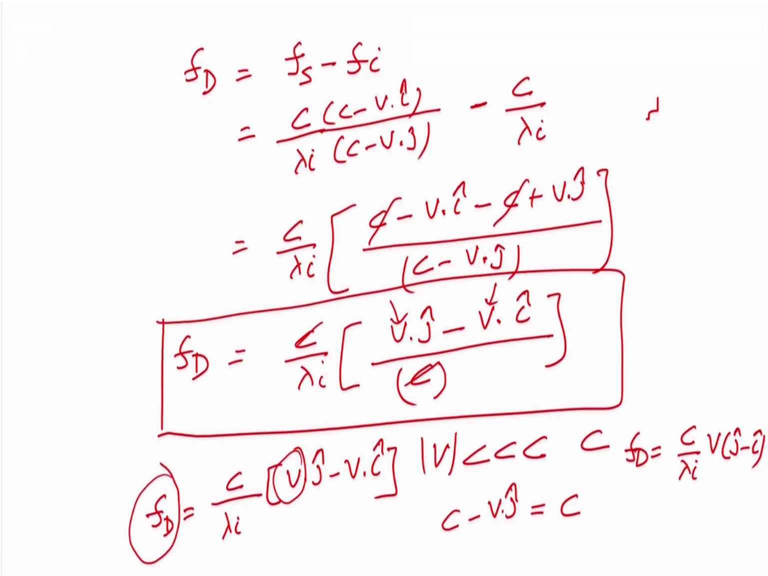

So, Doppler shift in the frequency will be what? How much is the light which has been scattered, minus how much light which was incidental earlier. So, that is the droplet shift. Now if you do that, fs the way we have calculated is nothing but c upon lambda i into this is c minus v dot j upon c minus v dot i. You see that, that is the this sorry this is I and j opposite way around. So, this is i, and this is j.

So, this will be i and this will be j, this will be j. So, v i and j and this will be minus, fi is equal to c upon lambda i. So, we can take c upon lambda i out, and what you will get? You will get c minus v dot i minus c plus v dot j upon c minus v dot j. This you will get, this cc will be cancelled out, and you can write it as a c upon lambda i is equal to z dot j minus v dot i upon c minus v dot j. So, you will get this value. And that is what is the Doppler shift in the frequency. So, this will be the Doppler shift in the frequency you will get. And that Doppler shift in the frequency if you will see is directly the function of velocity. So, this is a directly the function of velocity.

So, we can calculate if I can measure the Doppler shift, I can measure the velocity of the fluid. And that is the basic principle is being used. So, what we do? We incidental light we c it with some particles, now these particles are moving with the velocity of the fluid, now this particle is going to scatter the light, what we need to do we need to measure the incident of the light without the presence of the particle, we need to measure the light in the frequency of the light, intensity of the light, inter presence of the Doppler shift or inter presence of the particle, or in the presence of the light is scattered, the difference between these 2, the incident and the scatter is going to give me the Doppler shift frequency, and once you have a Doppler shift frequency, you can directly correlate it with the velocity. So, in that way you can do.

Now, if I assume and for most of the flow, it is always correct and particularly for the case of a light, this is definitely correct, that all this v is very, very small than the speed of light. So, say b mod of v, I am sticking is very, very less than the speed of life. And that is true for most of the applications we are going to discuss. Not most for all the applications but clearly if you are using laser. And that is the n in the reason that why we are using the laser. So, if this is true, then what we can do? We can say that c minus v is going to be equal to c, this value c minus v dot j is going to be equal to c. Because the light value of velocity is very, very high compared to v you subtract a very small value the value remains same. So, this will be equal to c.

So, then this will be equal to c, this c and this c will be cancelled out, it means this I can remove it with c only. Look at this I can remove the c only, this and this c will be cancelled out this is lambda i. So, whatever you are going to get, you will get fD is equal to c upon lambda i into z dot j minus v dot i unit velocities. So, this is the directional component, and you can find it out that, how the Doppler shift is dependent upon the velocity. Now if you fix a light intensity or source of the laser, your lambda is fixed. C value is fixed. So, finally, if you somehow measure the fD you can easily measure that what is the velocity. And this you can write it simply fD is equal to c upon lambda i, this will be v j minus i unit vector. So, that is the way it will be there, and you can find the velocity in the direction of the scattered, velocity in the direction of the incident, and you will get it that, what will be the overall velocity.

So, that is the principle, basic principle of measurement of the laser Doppler anemometry. So, what is the basic principle? What we will again discuss, that in LDA effect of the Doppler shift is being used or Doppler shift effect is being used to measure, the velocity of the fluid, the flow what we do is seed, we see the flow with a small tracer particles, that tracer particles actually with moves with the velocity of the fluid, we keep the tracer particle specification such that that it can easily represent the velocity, or then easily mark the flow of the fluid by keeping the particle size very small by keeping the stokes number very, very less, and by keeping the particle neutraly buoyant.

So, if you do all this, you can follow or you can assume that your particles are actually following the path of the fluid, which velocity you want to map, you can use that, this you can see the particles at this tracer particle, that tracer particle will be moving inside, you form a narrow beam of the laser; which has been focused on an object or on a measurement volume, you make that. So, what you do? You take this laser light

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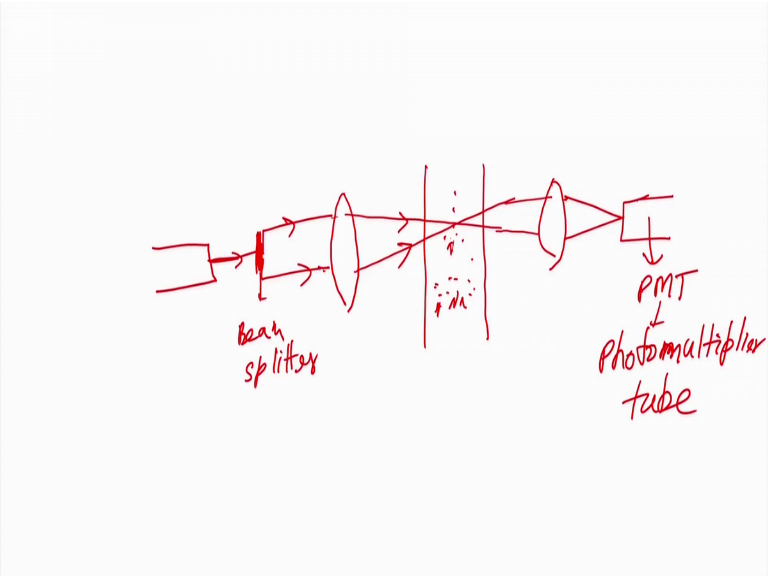

You take a mirror something like this, you split that light in 2, or you use a beam splitters, you take a mirror, you incident it, you take a say let us say, beam splitter; this is the beam splitter. You break it in 2 beams or a split it into the 2 beams. You take a lens, you focus these 2 beams at a particular location inside the flow of interest. This is inside the flow of interest.

Now, what you do? You measure this response by using a lens again. You measure this response on the receiver. Now this receiver is nothing but a photomultiplier tube. So, this is called PMT that is nothing but photo multiplier tube. So, you receive that signal. Now how much shift, if you seed it with the particle, as I said, this particle will be moving, if you seed it with some particle, this particle will be moving, and once they will come here, they will shift the frequency of this incidentally rage, or this incident light. And that shift in the frequency, you can measure the Doppler Effect, and you can calculate the velocity. So, what you need?

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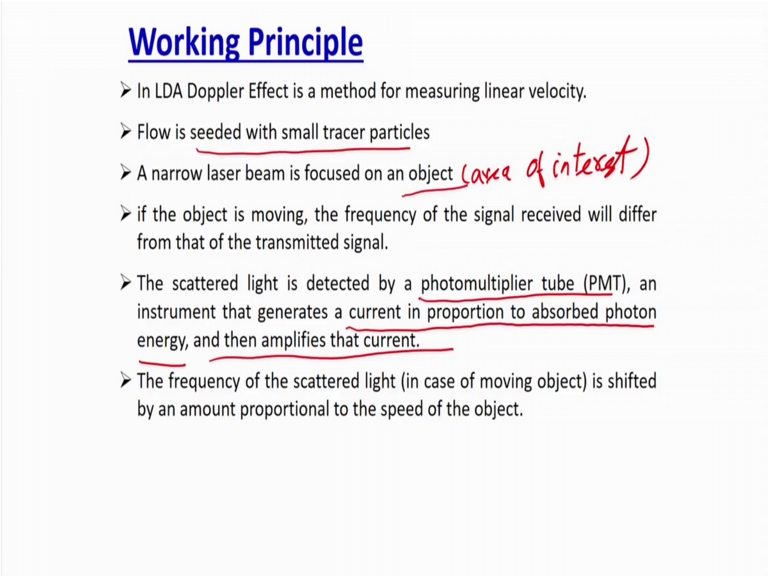

We are using the Doppler effect to calculate the velocity, we need the seed particles which are small enough to track the motion of the fuel fluid phase huge velocity we want to map, we incident a narrow beam of the light on the area of interest or an object which I said we can say on an area of interest, interest and if that object is moving say on which you have incidented if that object itself is moving, or the particle which you are seeded once they will pass through that in measuring volume or the area of interest, what will happen? The frequency of the signal received will differ from the transmitted signal. So, whatever the frequency we have transmitted will now will be different from the without having the particle in the source. So, there will be you will see the difference in the frequency or different in the signal.

Now, that scattering which should we take place because of the presence of the particle, can be detected by a photomultiplier tube, which is an instrument that generate a current in proportion to adsorb photon energy. And then amplify that current. So, we sent it through a photomultiplier tube, and the photomultiplier tube there is a electronic circuit inside, where there is amplifier is also there. What it does? Actually, the moment gamma or kind of any photon incident on this or any light source incident on this, it goes to excited state that excited state once it comes back, it emits a photo electron. That photo electron goes to photo cathode. It generates the electron that electron passed through the several diodes placed inside, to intensify the current signal, and current generate a current. So, the amount of current generated is equivalent to the energy of the adsorbed photons. So, if the photons adsorb is of higher energy, the current generated will be also higher.

So, in that way it is being proportional to this the light is scattered, and that that you can measure, and the amount of the scattered light actually you can calculate. Now once you have the amount of the scattered light, we know that, the frequency of the scattered light, A in case of the moving object is directly amount to the velocity or speed of the object. So, we can calculate their speed. So, that is the very basic principle whatever we have discussed till now is for the LDA velocity measurement. So, what you want? You want to measure the Doppler shift in the frequency.

It means you want to major that fD whatever we were talking about earlier. So, fD depends on the speed of the object, or speed of the seed in particles, which velocity you want to track. It also depends on the direction of the particle motion that which direction the particle is moving, because once it will move, towards the source or towards the receiver, then what will happen? If it is moving in the direction of the incident of the light, it is will be negative the Doppler shift will be less, if you are moving opposite of a Doppler shift will be high or the intensity will be high.

So, in that way, in that way it depends on the direction, it also going to depend on the wavelength of the light. So, therefore, for the idea you need to choose a proper light of proper wavelength of the light to improve the signal to noise ratio.

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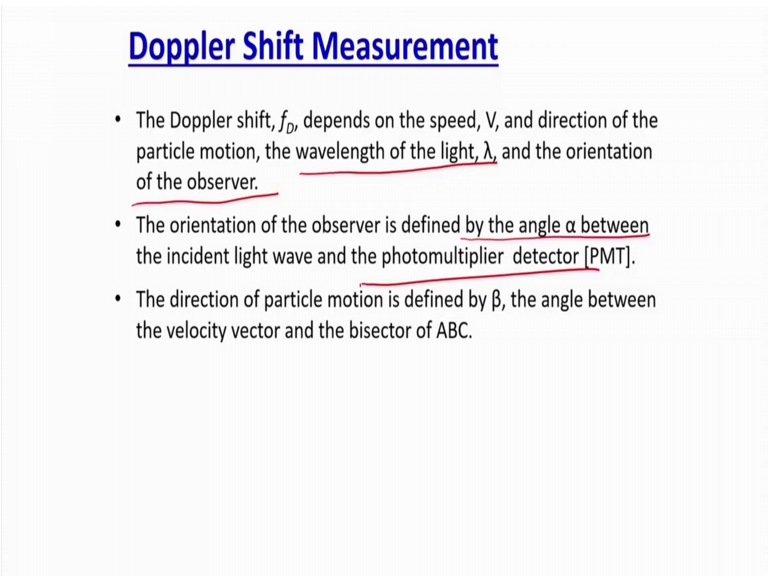

And the orientation of the observer that at what direction you have oriented the observer; and we will discuss that, depending upon the direction of the detector or the observer, we can classify different type of LDA so, that is going to depend on that the orientation of observer is defined by an angle alpha between the incident light and the photomultiplier tube. We will discuss it to what it is saying; the direction of particle motion is defined by the beta angle and this beta angle between the velocity vector and the bisector of ABC.

So, suppose if there is light I have this figure here.

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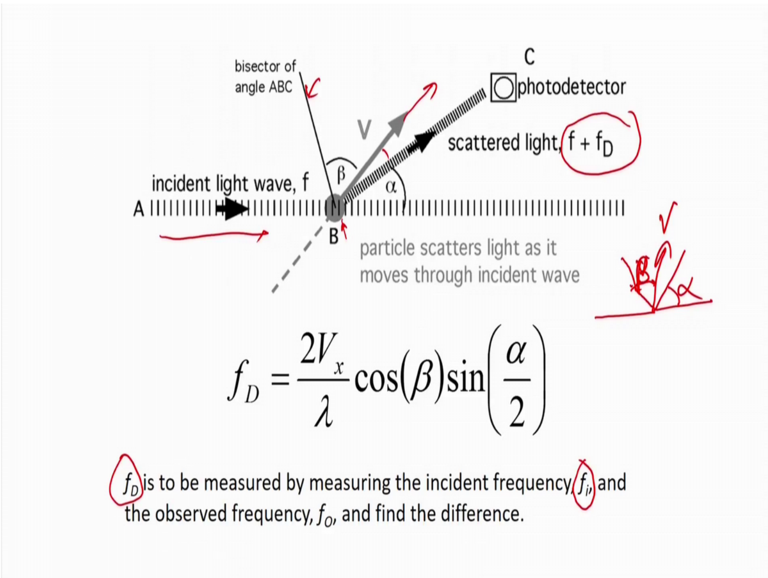

Suppose there is a light which is being incidented. So, this is the light which is being incidented. So, this is the light which is being incidented on a moving object, this object is say itself is moving at a velocity v. So, this object is moving in this direction with a velocity v. And there is a photo detectors which has been placed somewhere at this line. So, what will happen? Once the wave will be incidented, since there is no particle, the there will be certain intensity which you will record on this photo detector. Now once the particle will be there, because of the particle velocity, this kind of light incidented on this this object will be scattered.

So now what you are going to see? Are there you are saying seeing the f? This now you are going to see that I have plus fD. So, you are going to see that what is the frequency, plus whatever is the Doppler Effect, frequency is there. So, that what you will see that as I scatter light frequency. And let us assume, if this is the alpha, where alpha is the angle between a b and c, it means the angle between the incident light and the photo detector, if the beta is angle between the line which bisect this ABC's. Suppose this is ABC, the line which is bisect this which is the driven by this thing. This is the v. And if this is the velocity that is the v he has taken. That is the angle sorry beta, this is the velocity vector. And this is the angle alpha; which is the angle between the incident light and photo detector just like ABC. That is the angle alpha, if you take a angle between the line which bisect the ABC with the velocity v, that is beta.

So, in that case if you do the trignometry, and if there is any problem we can discuss; that if you do some trigonometry you will get that fD is nothing but if this will be equal to 2 into vx upon lambda into cos beta into sin alpha by 2. So, you can do some just calculation, and you will able to calculate it that y it comes to sin alpha by 2, and cos beta. So, what we have done? We have taken the angle in this effect.

So, this will be v cos beta, and then this will be sin theta because in this direction you want to say. This will be the in the direction of sin. So, this is alpha, this is 90. So, this will be going to be 90 plus alpha. So, that will be cos 90 plus alpha that will be equal to sin alpha by 2. So, if you divide it by 2, because we need to take this much. So, we need to take this angle. So, that is what is the alpha by 2.

So, what we want? We want to measure the fD. And we want to measure the fi. So, fD we want to major ideally, now every can be measuring the fi, and measuring that fs. If we know that fs, what is the scattered frequency? What is the incident frequency? We can calculate that what is the f t. And that is the whole principle of measurement.

Now, the problem in this case is that, if you have a single source and single light. The single light, they we face several problem. And we will discuss that what is this if that problem. So, what we are doing? We are having a single light; which is being incidented on the moving object. And we say that if the moving object with a moving with the velocity b and it makes the alpha angle between the moving incident object whatever it is moving here to the photo detector, where the photo detector observer is placed that is the alpha.

Now if the velocity is moving at a v, we define an angle beta; which is nothing but the bisect angle bisector of the angle of ABC, it means the incident, light incident on the observer through the photo detector, that is the angle. So, that is the beta, and this is alpha then fD is I wings given as 2 v x upon lambda or cos beta into alpha by 2.

So, in that way you can give this.

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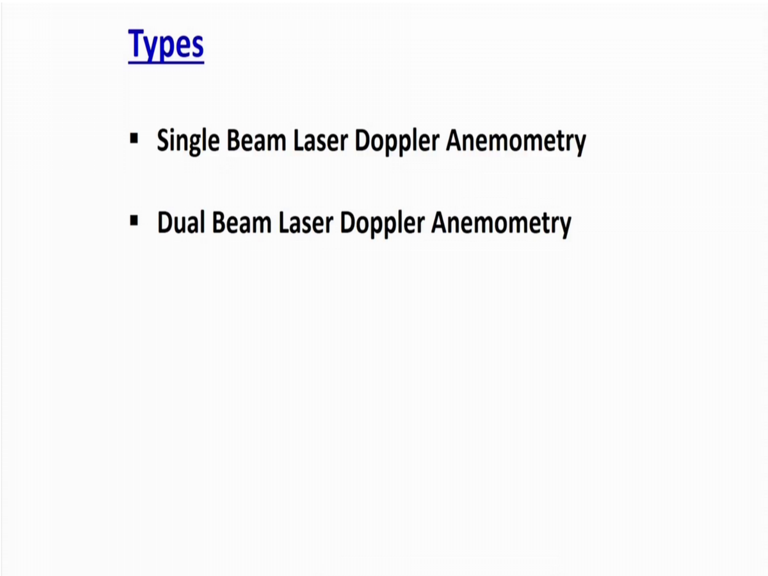

Now you can divide as I said that this is for the single light, you can divide your LDA in the 2 parts. One is the single beam LDA, and then the dual beam LDA. Now what is single beam LDA? Single beam idea is where you use the single beam to measure the velocity.

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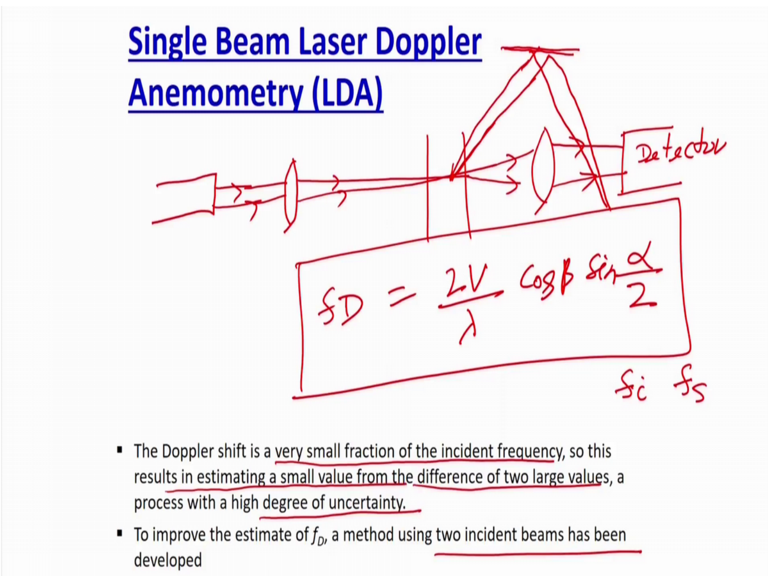

Now is this technique has it is own advantage and disadvantage, this whole tag both type of the single and dual. And we will discuss that. So, what is the single? In this you use a single light source or single beam. So, what you do? You have a light source, say this is a light source. And that light source you actually make fall. So, this is the light source. You use the lens, and you focus this light source on certain location. You are focusing this light source on the second location. And then by using this lens, it is again going back to the detector. This is my measurement volume. And it is going back to the detective.

Now, what we do? We need to measure what? We need to measure that how much is the frequency was there incidented, that we can measure. How much is the frequency which was recorded before the scattering? That we need to measure. So, we need what we need to measure the reference frequency. So, that which is being there, without having any flow or without the having the particle inside, that is the frequency which we need to measure.

So, for that what we do? We actually use one mirror, which will be actually reflecting the light, and we use this mirror in some angle alpha, or some angle. Now this mirror what it does? Suppose, this is the mirror, I will meet the mirror at certain location. So, this will be the light which will be coming. I meet the mirror somewhere here, or somewhere here little bit. And then that mirror is actually incidenting the light somewhere here. So, what will happen? You will get that scattered light mixed with the light which is being now kind of incidenting earlier.

So, that the difference, if you do that difference you will get that fD value. So, you will get directed that what is your fD. So, that will be difference. So, I took a laser light, I put a beam splitter break it in 2 beams and focus them with by using a lens. At a particular location where we want to measure the velocity, we seeded the flow with the particle, once the particle is there, it will scatter some of the light, scatter some of the light, that will be catched by the lens, or deliver lens and being thrown to the photo multiplier tube or detector.

Now, at the same time, we also measure that, what will be the frequency of the light which has been incidented on the receiver, without having any particle inside. So, what we do? We put a mirror, we record that frequency, whatever they being scattered this or whatever is being transferred in all the direction and then we focus it back to the detector or to the PMT. And before going to the PMT, these 2 waves are mixed. So, what do you get? You get the fD value. Now once you have the fD value, we have already developed the formula for calculating the velocity, and that formula is actually nothing but fD is equal to 2 z upon lambda into cos beta into sin alpha by 2.

So, you can measure the velocity. Yeah, you know the meter now, you know the alpha now, you can calculate it. So, you know all these things. You know the beta, you know the alpha, you can calculate that what will be the velocity. Now the certain drawback this looks very simple that you use a light you split it in 2 parts, and then you kind of put it in the receiver, and you record that. But there are certain drawbacks and the drawback is that the Doppler shift is very small fraction of the incident frequency.

So, what we are going to measure here is the fD. And that is the very small fraction, or very small frequency of the incident lights very small fraction. So, this result in estimating a very small value from the difference of 2 large values; what we are measuring? We are measuring the f i what is the incident, then we are measuring the fs whatever is they scattered. And from difference of these fs minus fi we are calculating the fD.

So, what we are trying to do? FD value is definitely going to be very small. But the value of f I is going to be very high, f s value is also considerably high. So, you are getting the fD by subtracting the 2 large values or 2 very big values. So, what it will do? It will make the result of this problem is uncertain. Why because this there can be inaccuracy generated because of the way it has been calculated. And this the process generate the high degree of uncertainty in your velocity measurement.

Therefore, to improve the velocity measurement further, what we do? We use us incident the beam instead of one we use the 2 beams. So, therefore, we use 2 incident beam method to improve this condition in the velocity measurement, or to remove this uncertainty in the velocity measurement. So, the dual beam idea is being developed.

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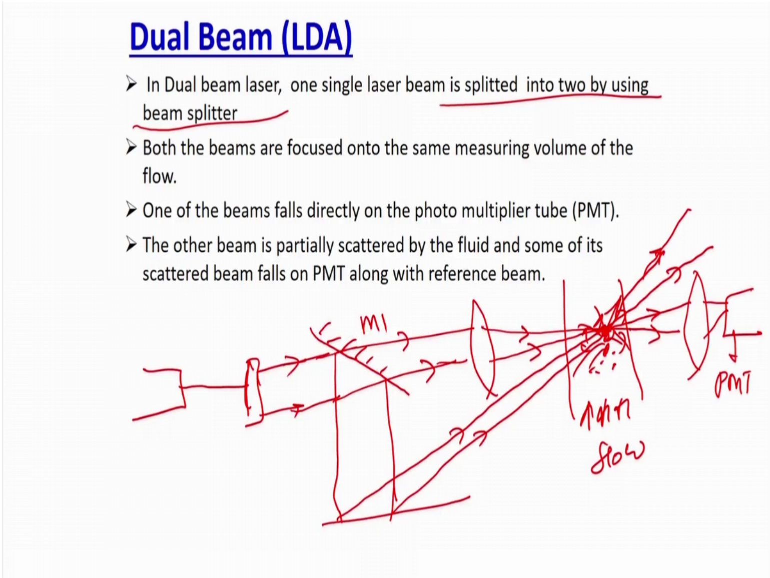

So, I hope it is clear that why we are developing the 2 beam. Because what is going to happen? We are going to calculate the fD, by subtracting the fs which is scattered frequency minus fi this is the incident frequency. And to do that what we have done? We have already mix the 2 phase, 2 this frequency, at this place before it goes to the PMT. So, you have to measure that. Now if suppose, what you will happen? You will generate some error. Now why you will generate some error? Because you are calculating the fD Doppler shift from the 2 values which are very high, this kind of incident light frequency, minus the scattered light frequency. So, you are calculating from there. So, what will happen the sensitivity or the accuracy of this fD measurement will not be that much good.

And therefore, what you will see? You see a high degree of uncertainty in your measurements; therefore, to overcome this, what we do we incident the 2 beams? Now what happen if you incident the 2 beams? In dual beam, one single laser beam is splitted into 2 by using the beam splitter. So, what we are going to do? We are going to use a beam splitter to split the beam in 2 parts. So, suppose this is the laser, we use a mirror to use a beam splitter. So, this is the beam splitter. Now beam split will split the beam into beam splitter. Now what we do? We use a mirror. Once you use a mirror, what will happen? This sunlight will go on this side, some light will come on this side.

Now, this lights which are going here, will be actually again fall on a lens. And that lens will actually make it converge. That lens will make it converge which will again go to a lens, and then it will fall to the PMT. So, this is a PMT. So, this will again fall and go on the PMT. This is my, the area of measurement in which you want to do. There the flow is going on it in this direction, and this is the area of maintenance, or area of measurement. Sorry, now this light, whatever is there, this is the mirror, which you have used similar m 1. Now again one mirror is being used again, one meter is being used.

And this light also incident at the same location. This light is also incidented on the same location. So, this and this is the direction. So, this light will be incidenting on this. So, what we do? We take a single laser in the dual, dual beam also; we split the single laser in 2 different laser, by using a beam splitter and the mirror combination.

Now, both the beams are focused at the same location, and that location is the measurement volume or the point of interest, where we want to measure the volume, the other particle the particle, which is being scattered, now suppose we put the particle here, we dump it with the particle, what will happen? The particle will do the scattering of both the lights.

The particle will be scattered on both the lights. Now the scatter, which falls on the PMT along with the reference will be different for both the beams, why? Because the particle is going to make 2 different angle from both the beams and therefore, the scatter which will be the path, the beam which is partially scattered by the fluid is going to fall on the PMT along with the reference cell, and that will be different for different beams. Why? Because the incident angle is different so, that is the basic principle is being used for the dual beam LDA. And that is the major advantage also. So, what happened that?

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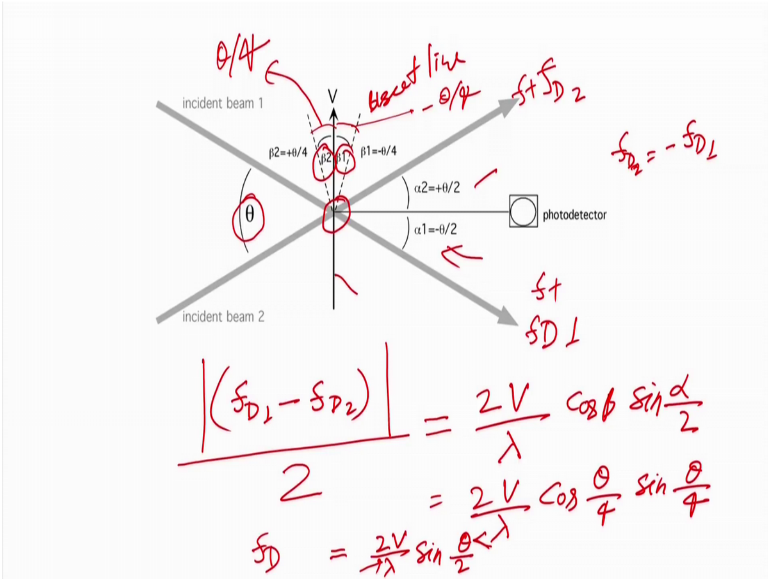

If you are using this, what will be happening? So, this is my incident light. A receiver is placed a photomultiplier tube is placed in the same direction.

Now, this is suppose it has been placed here in this way. Now second light which will be coming here on this side is will be incidenting at the same place. So, this is the place where it is incidented. Now suppose this is the place, where it is incidenting this is the velocity which is moving up. So, what will happen? You will form an angle from this incident beam to the photo detector. That is say alpha 2. You will find one angle is alpha 1. Alpha one will be, and if the theta is the incident angle, then what will happen? Alpha 1 will be equal to minus theta by 2. Because this is below this 0 line, alpha 2 will be equal to cos theta by 2, because it is above than the 0 line.

And then we are defining the angle beta, and the angle beta is nothing but the angle between the velocity vector to the bisect line. So, suppose this is the intersect or bisect line, then this will be the bisect, and the beta will be the angle between these 2. So, this will be the beta 1 and this will be the beta 2. Now if you do the trigonometry little bit you will find that beta one is nothing but this is equal to minus theta by 4, this is nothing but equal to minus theta by 4. And this is nothing but is equal to theta by 4. So, that is the way this has been defined. Now if I write that how much is the Doppler shift you will get, what you will do? You will see major both the intensity. You will mix then, you will measure both the intensity on the photomultiplier tube. So, what you will see? You know we are seeing the 2 Doppler shifts. One Doppler shift is in this fD 1, say this is fD 1. You will see here. One Doppler shift you will see in the fD 2. So, that will be fD 2.

So, fD 1 minus fD 2 you will get these 2. And you will measure these 2 Doppler shift difference between these 2 Doppler shift. And that difference in these 2 Doppler shift will result in terms of the velocity. So, what you have done? Instead of measuring 2 quantities, which are very big say incident frequency, and the scattered frequency, now you are measuring the Doppler shift for beam 1, Doppler shift for beam 2, you are subtracting them to find it out effective Doppler shift on this. And that will be correlated with the velocity of the observer or velocity of the particle.

So, what you are going to do we are going to calculate fD 1 minus fD 2, and that fD 1 by fD 2 is what is if you will see that fD 2 will be nothing but, it would be equal to because the incident frequency is same fD 2 will be nothing but equal to minus fD 1. So, in that case you can say that, if you want to find the overall shift in the doppler, that will be nothing but this will be divided by the 2. You got here my point why? Because fD 2 will be equal to minus fD 1, the incident beam frequency is same. So, what is going to happen? Only the direction is different, but it is going to have the equal magnitude. So, fD 0 is going to be the fD 1.

Similarly, like for this, this will be f plus fD 2 here, it will be f plus fD 1. And we are now measuring that, how much a relative change is there. So, that will be f d 1 minus fD 2. And this will be divided by 2, because this is the effective. So, fD 1 will be equal to actually minus fD 2, or fD 2 is equal to fD minus 1. We can replace it will get 2 fD. So, that will be the overall this volume. So, this will be equal to as we have discussed 2 v upon lambda, now what is the angle in this case? So, earlier this was the one angle, and we say that is the cost beta into sin alpha by 2. So now, what will be the alpha angle? Alpha angle is it is given theta 1 by 4. So, this will be 2 v upon lambda, this will be cos beta is theta by 4, that will be theta by 4, this will be sin theta by 4.

Now, if we are talking about being one or beam 2 it can be plus or minus. So, even that does not going to change your result, because cos minus theta is equal to cos theta, cos psi minus theta is equal to sin theta. So, you are going to get this value upon 2. So, if you solve this, what you will get? You will get 2 v upon lambda into sin theta by 2. This is cos theta into sin theta, 2 cos theta sin theta is equal to sin theta 2 theta. So, that is what we have used, and you will get the fD value. So, it means what? If you know the v if you know the fD for the dual beam if you know the incident light, if you know the frequency or wavelength of the incident light, you can calculate the velocity by dual duel beam. You can calculate the same for the single beam. But the single beam the problem as I discussed the problem is that you will see that you get the fD value by subtracting 2 large values.

So, your uncertainty will be very high, your accuracy will be compromised; here you are getting the fD values by 2 small values f plus f d and f plus fD 1 by this way. So, you are so, whole sensitivity is there, now you are calculating that if you subtract this, you will get the fD 2 minus fD 1 or fD 1 minus fD 2. Now we know that how much is scattered will be there that will just depend on the direction. So, direction will be opposite, and that is why fD 2 it will be equal to minus fD 1 we calculate the fD.

So, this gives you the higher sensitivity, the better accuracy in case of the dual beam is being observed compared to the single beam. The formula remains same. So, you use these values to calculate that what is the fD value here.

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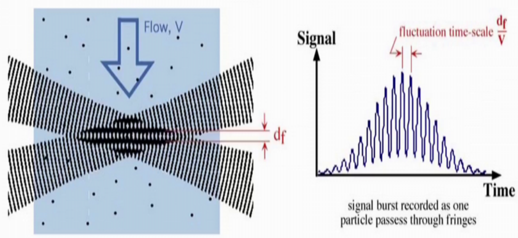

Now, we will discuss this part, I think later on that, how to calculate this? How to do the signal post processing in the next class, but the basic principle of the idea, whatever I said is remain same you measure the Doppler shift in the frequency, and that Doppler shift in the frequency is going to be the same, or is going to be proportional to the velocity of the fluid of velocity of the particle, which is seeded in the fluid. And that velocity of the particle is equal to the velocity of the fluid. So, you can measure the velocity of the fluid. And we will discuss about the signal processing advantage and disadvantage of LDA in the next class.