Measurement Technique in Multiphase Flows
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Lecture - 07
PIV and Positron Emission Particle

Welcome back. In the last class whatever we were discussing about is PIV and we have discussed about the measurement principle and the operating principle then how to process the PIV images to get the velocity map.

So, whatever we have discussed about the PIV reconstruction algorithm, we said that what we do in this kind of PIV; we take two images in a very short duration, we kind of divide the images in a small pixels and then in each pixels we do the FFT for both the pixels, for both the time and then we cross correlate both the images and based on the cross correlation; we do the inverse FFT and try to find it out the overall displacement. So, from that displacement we get a displacement peak and once you have the x and y location you can calculate the V x and V y by delta x by delta t and delta y by delta t.

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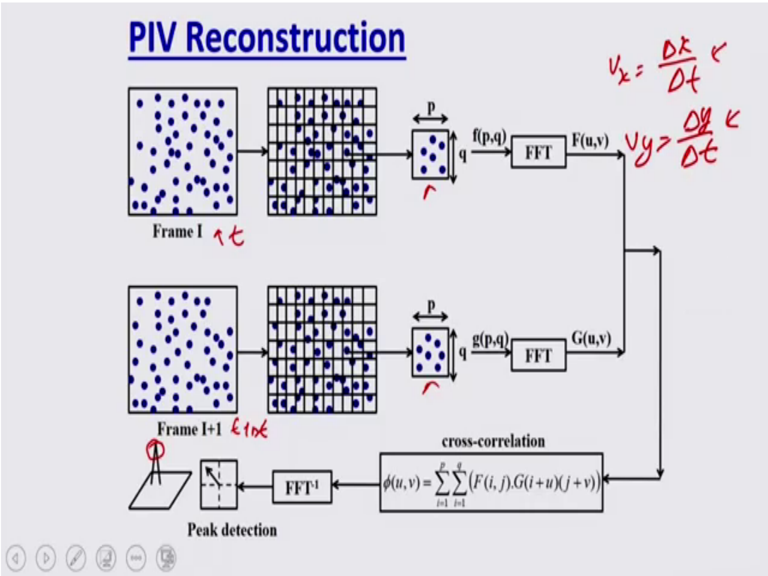

So, this was the reconstruction principle of the PIV, this is a very good technique it can have a very high temporal resolution, very high spatial resolution and it can be used for kind of you know; it is not it do not disturb the flow and it can be used for many of the systems. So, but there are certain factors which affect the accuracy of the PIV experiments, and one of the factor is that laser intensity that what is the laser intensity and laser energy and you are using and laser wavelength. Because whatever you are going to do; you are going to form a sheet of the laser, your particle will get eliminated because of that and your acquisition is based on that how fast your laser is generating the pulse. Further again as I discussed earlier that this is a optical based technique.

So, your laser light penetration how till how what depth you will able to major in the three dimensional column, will depend that what is your energy of the laser. So, if your energy of the laser is low you will not be able to penetrate through the longer distance; so one need to be very careful about that. Then the second important thing is the tracer particle; so, first we will discuss that whatever was the component we require in the PIV experiment to do the PIV measurements and then we will try to see that what are the critical elements?

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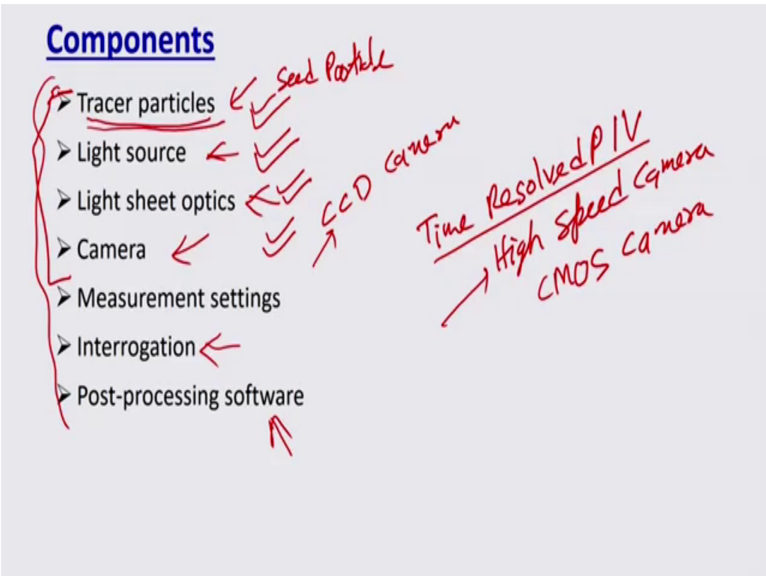

So, definitely the thing which we require is a tracer particle or sheet particles which you are used to feed the flow and which will be eliminated in the presence of the laser light. Then you need a laser source and laser sheet optics; so, you will have a laser, laser again I just I said that laser energy, laser wavelength is very critical for the PIV measurement and depending on the application, you have to use a suitable energy as well as suitable wavelength if that is not there your data will be noisy.

So, that you need to do then you have to generate a you need a sheet optics, which will be generate a sheet of the laser. Then you require a camera again depending upon what type of PIV you want to do, if you want to have a time resolved PIV that is called time resolved PIV and this is very famous nowadays you need a very high speed camera. So, what you are going to do? If you want to see that how the flow is resolved with the time, it means that with the time how the things are changing and as I said that in multi-phase flow the time resolve PIV is more applicable because multi-phase flow the things changes with the time with the location.

So, if you do not do a time resolved PIV you will get the velocity vector, but we will not able to get that how this vector is changing with the time. Particularly for a condition with the change there is the flow condition where velocity is very high. If the velocity is very high the change in the flow will also be very rapid. So, in that cases you need a time resolved PIV; in the time resolved PIV you use actually a CMOS camera and this CMOS camera is generally a very high speed camera, which will be operated at a very high frame speed say in the rate of 1000 or 2000 or 4000 frame per second. So, you require the, you get the kind of photographs at a very high frame rate, and based on that if you get it that you can analyze the images and then you can get that with the time how the velocity field are changing.

So, the time result PIV is there or if you do not want a time result PIV then a CCD camera normal camera kind of this charge couple device it is called CCD camera can be used. Definitely CMOS camera which is high speed camera is costlier compared to this CCD one, but you can do that high speed imaging with the CMOS camera in the conventionally we use CCD, which is charge coupled device camera.

So, the camera is very critical in camera you have to see that what should be the resolution of the camera, what is the interrogation area you want to investigate. So, based on that your camera focal this and you have focal length your certain speed and all those parameters need to be changed, you have to buy a suitable lens. So, that you can change zoom the camera on a particular spot or you can have a kind of if you want to have a bigger interrogation area, then you have to keep the camera a little bit far from the surface so, that you can cover the entire range.

So, depending upon the application you want complete map, you want a very small zone to be focused you have to buy a suitable lenses; you have to maintain the camera you have to keep the camera a certain distance from the location so, that you can do the focus ok. So, based on that the camera requirement is also very critical, you need to have a camera which should be very good where the certain. If you are operating in the is you are not doing a time resolved PIV your certain speed should be very high, if you are using a high speed PIV or time resolved PIV is. So, the camera frame speed and resolution should be very high.

So, that is the camera requirement then you have to do the measurement settings that you have to set the laser sheet you have to fix the camera and all for that you need the settings you need the supports you need the isolation table, which can remove the vibration if there is any vibration there and then you have to have the interrogation area you have to do and then you have to select a suitable area that where you want to focus and then you have to use a post processing software to get the velocity field.

So, that post processing software will do the same job as we have discussed you can write your own code or you can use a software commercially available software for the post processing. So, these are the major component; out of this component definitely the tracer particle, light source sheet optics and camera these four are very very critical this four are very very critical and the accuracy of the PIV will depend on these four ok.

So, in that light source we have already discussed sheet optics is something which we have to make the sheet ok, that should be very good synchronized properly your sheet optics and your camera or your laser should be synchronized properly. So, that you get the photograph at the light time. The camera speed should be very high or very good resolution you should use the camera.

So, that is there, but one of the major from flow perspective one of the critical parameter is the tracer particle. That what type of tracer particle you should use and as we already discussed earlier during the introduction classes, that if your tracer particle is not of the right size then what will happen it will have its own motion. So, if I say that the response time is say very very low then it will follow the path of the fluid if the response time is very high, then what will happen it will actually have its own motion, it will not respond to any change in the fluid flow.

So, the treasure particle preparation is very critical; and as we discussed in the LDA also that when LDA what we do we put the laser beam on the particle and we measure that the scattered light the light is scattering. Here also it is the same thing approximately you are using the laser light to illuminate the particle. Now if the particle size is very small then the illumination will also be very small the scatter will be very small and in that case this it is very difficult to record those particles on camera. If the size of the particles is very big then elimination will be high, but it will not follow the path of this particle or path of the fluid sorry.

So, in that case one has to be very choosey then have to be very selective while choosing the tracer particles, some of the particle which is widely used to map the gas and liquid by PIV is has been shown here.

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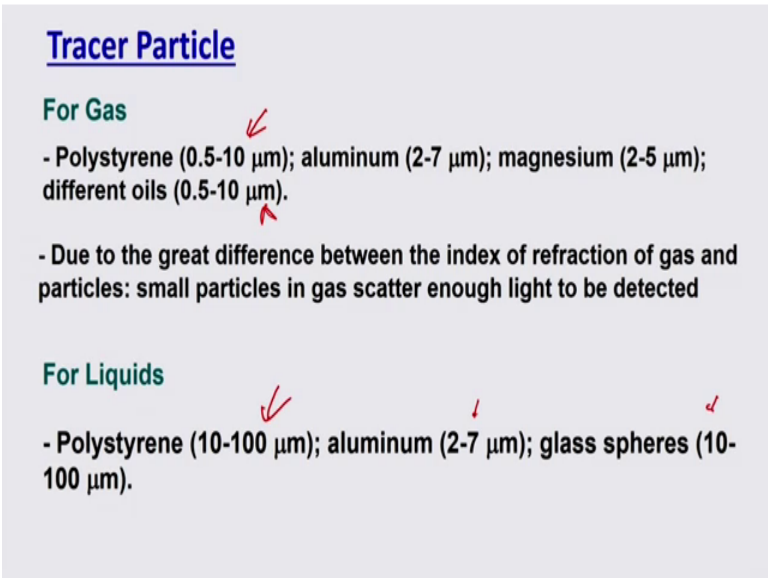

So, for gas generally we use the polystyrene particles of at sized 0.5 to 10 micrometer. For aluminum or we can also use the aluminum particle of two to seven micrometers sometimes, we use magnies magnesium particle of 2 to 5 micrometer, and we also use some oil droplets of 0.5 to 10 micrometer to track the air.

So, that these are used as a sheet particle. So, either it can be a small any oil droplet, it can be very small polystyrene beads it can be aluminum bead, it can be magnesium bead of different sizes ok. Now what is the good thing if you see here the particle sizes are very small, we are talking in the range of 0.5 to 10 micrometer maximum. So, why the particle sizes are very small here, the major region is that this air is have a very the refractive index difference of the air and the particle or the gas and the particles are very big and therefore, this small particle can also do the same refraction as the small particle can also give a refraction, which will be more than the air ok.

So, in that case we will get a proper contrast ok. So, in what will happen that, they will be more refraction there will be white bright color the air will come or the gas will come as a dark color. So, refractive index because they are very very different compared to the solid and gas and that is the advantage, and that is why you can afford to have a very small sized particle. While in case of the liquid that is not true and that is why you need to increase the size of the tracer particle; generally the use polystyrene and if you see the polystyrene sizes now we are using 10 times higher. It is 10 micrometer to 100 micrometer in the range.

So, that you get the more refraction your image quality is better or we can use a glass beads of 10 to 100 micrometer aluminum also can be used which is in the 2 to 7 micrometer because there the refractive index is different. So, if you see this generally the gases the particle size is very small, you can afford to do that because of the difference in the refractive index, in the liquid you need to increase the particle size.

Now once you are increasing the particle size, you need to be very careful that your stokes number is still very low or you can say the response time of the particle is very low, and it is following the path of the fluid one need to check that one way to check that is, to calculate the response time or you can solve the complete Basset Boussinesq Oseen equation BBO equation known, and you can see that how much extra error you will generate if you are using a finite size of the particle which diameter is little bit bigger. So, those exercise need to be done.

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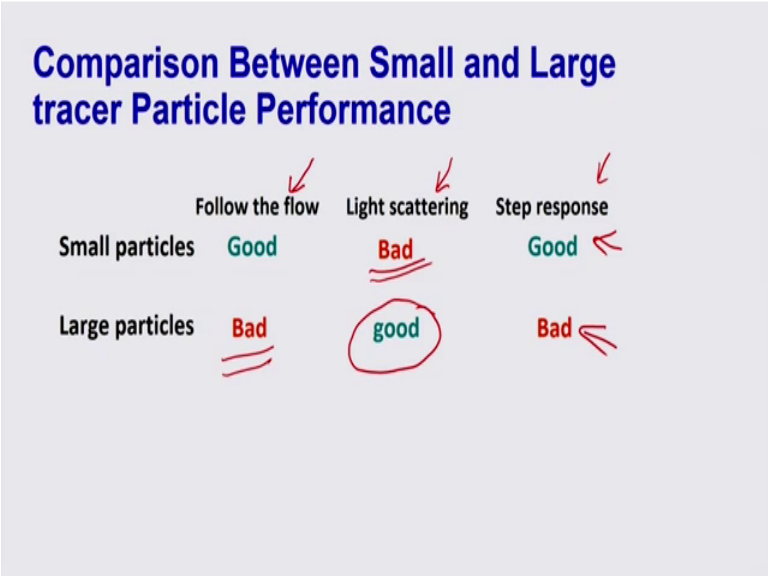

Now this is whatever I said that what is the performance where what you should choose your should choose smaller particle or larger particle as we discussed, that if the particle is small there is a three parameter on which we discuss it we discussed based on that how good it is following the flow, how good it is doing the light scattering and if there is any change in the velocity in the fluid velocity, how when it will respond to that.

So, in that three parameter if a small particle you are using, definitely it is going to follow the flow in a bigger good way only thing is the particle should not go on the a strong label that the Brownian motion is start dominating it will have its own say again. So, till you are making sure that you are not going in the Brownian regime, if the smaller the particle for the flow perspective it is good, but as we discuss the flow is the smaller the particle lesser will they scatter, and in that case the light optics wise the image quality wise it will not perform very good and that is why I will give a bad rating for that, that the smaller particle is not good for the imaging purpose.

And again because it is responding to the flow very well, if you do any change in the flow it will respond it better. So, that is the way if you go for the smaller particle, you can be assure of follow of the fluid that it is going to follow, the fluid any change in the fluid velocity it will respond immediately, the only thing is you have to careful is with the image quality. So, what you need to do? You have to increase your laser light intensity ok. So, that your image quality becomes little bit better. So, that is drawback because you have to use the high powered laser, high powered laser will create a safety concern too and it will be very costly. And then if you use the large particle definitely the chances that it follow the flow is low, it will have its own say and that is why the follow the flow will be bad it will not respond as quickly to change of the flow and that is why the step response will also be bad it will not respond that quickly, but the light scatter image quality wise it will be good.

So, it is always a tradeoff and depending on the application the accuracy you want, the error you can afford, the laser power you can afford the depth you want to investigate, you choose a suitable particle ok. So, this is the way you need to keep there in the mind that if you are choosing the smaller particles, what are the error you are going to encounter, what are the problem you are going to encounter. If you are using a larger particle what are the problems you are going to encounter. So, one need to be careful if you are using larger particle, we need to see the response time or stokes number of the particle and see that how fast it will able to respond to the flow.

So, with this we have discussed about all the parameter of the particle image velocimetry; obviously, there are several advantage of the PIV, even compared to the intrusive technique or invasive technique, and compared to the LDA, the most into on test part is that it gives the complete velocity map whole field measurement can be done while LDA was a point measurement.

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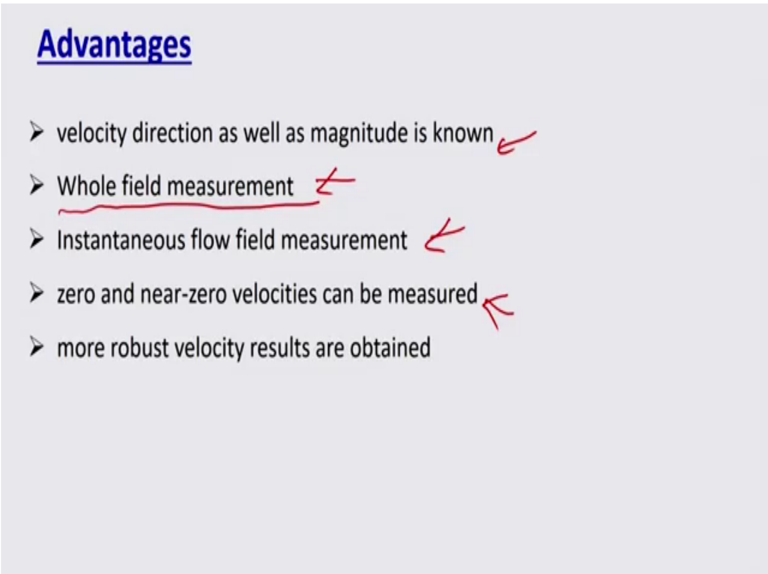

So, that is the major improvement which has been done from LDA to the PIV, you can get the velocity directions, you can get the velocity magnitude everything you can get here that what is the velocity and all and because you are completing the flow complete flow field you can also get the recirculation cell, structures if they are any forming in the turbulence or in multi phase flow, you can get those structures, you can get the circulation cells and all.

So, it can give you all these two parameters can give you completely it can give you the instantaneous flow field map, it can give you the mean flow field map. So, whatever we have discussed in the introduction what we require, it can give everything. If you are using a high speed camera, you can also find that how the instantaneous flow field map is changing with the time, how the fluctuations are changing with the time all those things you can get there or how the recirculation cells are structured dimensions are changing with that time, all those things can be done here then it can major the velocity which is zero or very close to zero.

So, it is a very low velocity is also there it can measure it if there is no problem like in h w a we discussed that with the velocity is very low you cannot use the hot vioano meters why because the heat transfer due to the convection may not be dominating natural convection may also play a role and then your whole calibration equation will be disturbed.

So, in this case there is nothing like that you can use it for even zero velocity or very velocity which is very close to zero, it is very robust technique and the velocity results obtained are very accurate or mostly accurate only if you are using the laser optics proper laser optics, proper sheet particles and the camera.

So, these specification if you are able to manage, then your spatial resolution your temporal resolution will be very high temporal resolution that will depend on the high speed camera if you are using a very high speed camera, your temporal resolution will be even better. So, that is the advantage of this technique, but there are several disadvantage too and as I said that the disadvantage first comes with the particle size and the lens.

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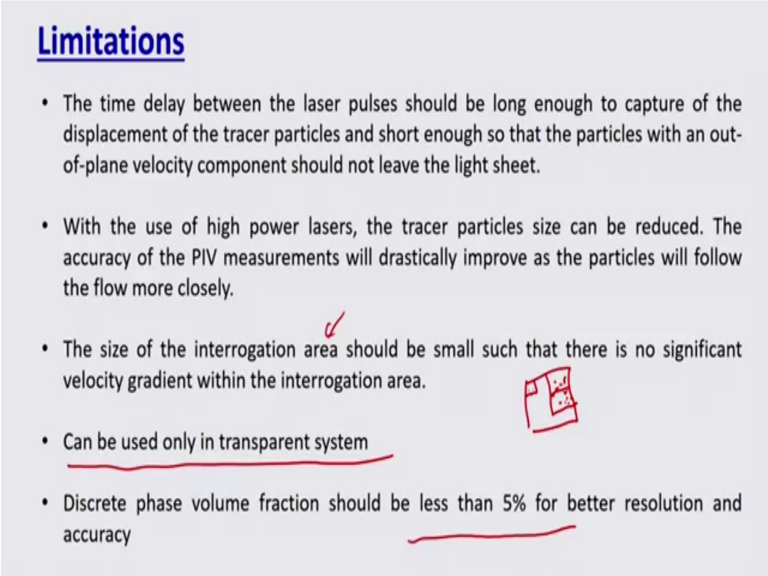

So, definitely if you are doing that lens pulsing, because we do the pulsing of this the pulsing of this should be one should be very very careful while doing pulsing the laser sheets or laser light. So, your pulse rate should not be very long ok. So, that it can actually should not be very long so, that the particle which want to go out of the view or it can go out of the kind of interrogation area most of the particle if it is going out of the interrogation area. So, it should not be long enough very long, it should not be very short also that the particles are not doing any displacement.

So, definitely the pulse light should be long enough to capture the displacement your it should be long enough that the particles move certain distance, and you are able to capture those distance with the camera which you are using, this with the resolution of the camera it should move such that that the resolution of camera allow you to measure the displacement of the particles, and at the same time it should not be the particle this delay should not be short enough.

So, that the particle goes out of the interrogation area, particularly the particle which are moving in the direction of the laser sheet thickness. So, then you go outside of the area or outside of the focus, and you will not get the image. So, what will happen? You will lose the particle between the two pictures and that will hamper your accuracy.

So, the laser pulsing rate should be very very accurate you need to be careful about that, then you have to also see that the power of the laser. So, you need a very high powered laser. So, that you can reduce the particle size as I said, but the high power laser the problem is that its very costly and there are safety issues also ok. And then the size of the particle should be small or will be small enough so, that it can follow the path of the fluid. If the size of the particles is not correct then you will get the velocities which is not the accurate velocity of the fluid, it will also have a say that how the particle is moving inside. So, particle will have its own size; then the size of the area interrogation area which we are using should be small such that there is no significant velocity gradient within the area.

So, if you are choosing a very big area then what will happen you will miss on the velocity field or velocity information. So, suppose this is your overall picture and if you are using the interrogation area in this one case this and in one case this. What will happen in this case the number of particle will be less, if the number image density is be less we as we said we have already discussed that the accuracy will be less. But at the same time if you use a very big area then what will happen the number of particles will be definitely increased, but there may be a velocity gradient within this area and what we are going to do? We are adding all the particle movement and then giving one displacement.

So, what will happen you will lose on the spatial resolution you will not able to get that whether the any change is there within that velocity that in area or not. So, therefore, the size of this should not be big enough, but its not be small enough to, we should have a considerable number of particle inside. So, that I can maintain a image density of between 10 to 15 at least. So, that is the again the limitation that you cannot go for very small, you cannot go for very big. So, you need to be optimal; it can be the major limitation is here that it can be used only for transparent system. So, if your wall is opaque or your system is opaque you cannot use this.

So, when I say system is opaque what does I mean? I mean that if suppose you are using a gas solid fluidized bed where the solid particle fraction bubbling fluidized beds say the solid practical fraction is in the range of 20 to 40 percent. What will happen all the laser light will be refracted from the wall you will not able to form any laser sheet, and if you are able to do any experiment the experiment will be limited near the wall only.

So, you are not able to get it that same thing is true for a very high bubble fractions, if you are operating a bubble column with a discreet bubble fraction of around 25 to 30 percent again the same problem you will see, the bubble will refract the light will not able to form the sheets and you not able to see through inside the column. Definitely the column where the wall itself is opaque, there is no question of using the PIV. So, this is the major limitation and that is why the PIV again like LDA cannot be used for a discrete phase volume fraction more than 5. So, if you have a discrete phase volume fraction more than 5 your resolution will be since severely hampered and you will be most of the time measuring, whatever is happening at the wall.

So, we discussed wall. So, what do we discuss till now is about the optical base technique, which is LDA and PIV the other also we have not discussed it like I have touched upon the PTV which is particle tracking velocimetry, these all are optical based technique and each optical based technique the major limitation is these two.

That you need a transparent wall, you need the transparent system tool. The once I say transparent system it means the fraction of the discrete phase should be very very small ok. So, that is the major limitation of all the optical base technique and that is why the next generation improvement has been done, a new techniques has been developed which is based on the radiation.

And that radiations are mostly gamma based radiation we know that the gamma based radiations can penetrate almost anything, and the losses in the radiation will be very small till you are not using a very thick wall to stop all the radiation. So, in that way that is the next phase of development, the radiation based technique and in that technique mainly two technique we will discuss, one is the positron emission particle tracking and another one is the radioactive particle tracking.

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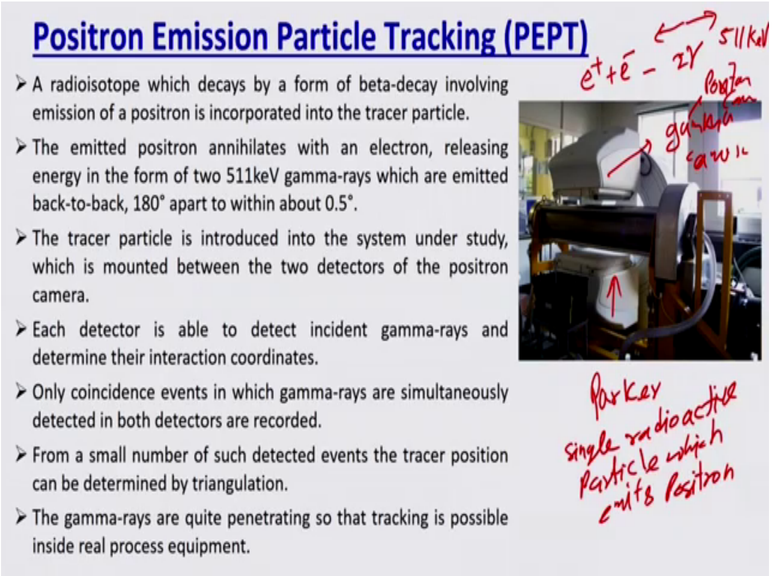

So, what we do in the positron emission particle tracking as the name suggest, that we are tracking the motion of a solid which is emitting a positron particles ok. So, what we do? We use a reactor of this kind this is the typical picture, which is taken from the Parker p Parker group, which is from ministry of Birmingham, we have taken it from his group photographs this is Parker paper in 2006, which is been published where they have investigated the roof clicking by using the PEPT. So, what the PEPT do? PEPT actually track a motion of a single particle single radioactive particle and that is a radioactive particle is actually the source of positron emission.

So, it track the motion of single radioactive particle; active particle which image positron. So, what it does, it emits the positron and that how we know that once a positron annihilates with the electrons. So, if a beta plus I will say or e plus annihilates with e minus it actually generate two back to back gamma rays. So, it generate the two gamma rays, which actually moves back to back 180 degree apart and the energy of this gamma ray is 511 K e V.

So, the we are using a source using a solid particle, which is a particle which is a positron emission source it emits the positron, once it emits a positron the electrons are available in the atmosphere or near about the system they interact with them each annihilation generate two back to back gamma rays, which are 180 degree apart of a energy 511 K e V.

So, that what is been emitted, now this gamma ray which has been emitted coming from the particle has been detected by the series of scintillation detector, which has been clubbed in a unit and we call it as a gamma camera gamma camera or you can say positron camera camera and they are nothing, but they are scintillation detector the array of the scintillation detectors.

So, you place it in the detectors and each detector is able to instantly find or kind of detect the gamma rays, which are incidented on top of the detectors. About the detector will discuss in the radioactive particle tracking technique because these are the same detectors we are going to use here you use the array of bulk detector, there we will use the individual detectors and will say that the functioning how the detector works, we will discuss during the radioactive particle tracking technique measurements.

So, the series of detectors are placed which are actually recording those gamma rays which are coming back to back. And we have a data equation system, which are recording only you those gamma rays which is simultaneously detected on both the detectors. So, this is one detector this is second detector. As we know that gamma ray will be emitted one 180 degree apart back to back of the same energy. So, suppose this is the detector we have placed there is a particle which is emitting the gamma rays.

So, ideally both the detector should get the gamma ray at the same time. So, only simultaneous detection we actually take it as a signal, if the situation is not simultaneous we do not take it as a signal. Why it cannot be simultaneous for some cases because there can be some reflection or diffraction of the gamma rays, because of the medium attenuation or medium kind of solids present or the medium the things present or the object present within the medium. So, those things we neglect we record only those gamma rays radiation, which is kind of detected simultaneously 180 degree apart.

Then we use the theory of angulation to reconstruct the position of the particle, I will discuss what is theory of triangulation. So, what we get? We get the Lagrangian track of the particle, we get that particle position with time this particle this positron particle will move inside the bed and as the fluid will move you will also get that position of the particle. So, we will get that for Lagrangian position time series of the particle. So, you will find that how the particle position is changing with the time; once you have the particle position we acquire the data for sufficiently long time.

So, that we have a sufficient statistics involved, and then that is being used to calculate the velocity how it has been done? That again the post processing part is other than the reconstruction of the particle is similar to whatever we are going to discuss in the radioactive particle tracking technique and that is why I am not discussing that here, we will discuss it in the next class

So, those things remain same and that is the major improvement if you will see. Because we are using gamma ray and because we are using gamma ray we can use this technique in the real equipment system, and the photograph which I have shown here which is from the parker group you see that the wall is made of s s. So, if you have a PIV system if you have LDA system definitely you cannot use it here, but because it will involve gamma radiation it can penetrate the s s you can have the signal recorded with you and this technique can be implemented.

So, detail of the technique again other than the annihilation part, this the way if the gamma ray has been generated, it is pretty much close to whatever we do in the radioactive particle tracking and we will discuss it there. So, what we will do we will discuss now that how to do the reconstruction ok.

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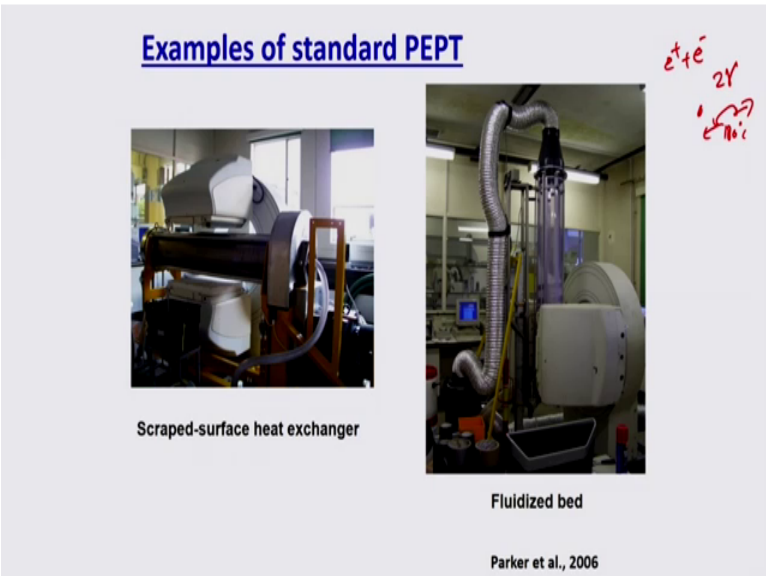

So, again to revise the basic what is happening that we are having a gamma ray we are positron we have a particle, which is emitting the positron that positron is annihilating with electron and it is generating two gamma ray which are back to back 180 degree apart and they are been detected on the gamma camera or the camera being used or the heat is this detector network is being used, to capture those gamma ray incidents.

We capture only those gamma ray incidents which are simultaneously recorded on both the cameras of both the kind of detectors, and then we use the triangulation theory to calculate the position. Once we have the position we do the experiment for sufficiently long time, and whatever you get that we are doing the experiment for sufficiently long time, you get that how the particle is moving with the time from there you can calculate by delta x by delta t the particle velocity, and then you can use the same information to calculate the mean velocity fluctuation velocity and all the other parameter.

So, about the post processing we will discuss later, we will discuss that reconstruction method which is being used in PEPT which is different from the RPT. So, these are the two photograph both are from the parker group, this is for horizontal clean rotary clean where the you can see them this is made of s s and this is for the bubbling fluidized bed where the same PEPT experiment is being used and this camera actually surround completely the zone of interrogation or the zone of interest, where you want to do the measurements.

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So, this is the about the PEPT for the reconstruction what we do the PEPT reconstruction as I said that you have a two detectors. So, big detectors are there. So, suppose this is the two detectors, there is one positron one electron they annihilate each other once they annihilate each other they generate two gamma rays which are 180 degree apart back to back 180 degree apart. So, what will happen both this will this travel within the medium and reach to the detectors and detector will actually record those incidents which is simultaneously detected.

So, you will have this then similarly, what you will get if you do this detector. So, you will get a line because now both are absorbing and the simultaneously, we know that one location is this and another location is this you can connect it through a line you will get a line. Similarly several such kind of annihilation is going on for all the position because the gamma decay; so, it is decayed kind of s decay; so, radiation.

So, the source decay happens at a very high rate ok. So, that rate you are also doing the annihilation and several such lines will be formed. So, say one line is this one line. So, several such suppose this particle is there this is detector, if I see this is sorry this is detector this is also detector, the several such incidents will happen this one line one line then there will be another line then there will be another line. So, several such incidents will be taking place.

We will see huge number of line and wherever all those lines will cut that will be the position of the particle and why we call it a triangulation because the two line cut will give the position the third line which will be passing through it will verify the position of this particle that this is the particle position.

And we do not use for three lines, we use several lines considering that how the particles are cutting in all the lines will cut actually at the same location, and that will give the position of the tracer particle and then similar things similar phenomena can be repeated for the longer time with the longer duration of experiments, and you can find it out that how the tracer particle is changing with the time. You can acquire the data at a very high frequency up to 100 hertz not as high as the HWA you can acquire here up to 100 to 200 hertz and you can get that how the position of the particle is changing with the time.

So, this is the reconstruction approach is being used for the positron emission particle tracking and then in this reconstruction you get after this that how the particle position is changing with the time. The other post processing remains same we will discuss in the next class, we will be discussing about the RBT post processing or radioactive particle tracking post processing ok.

So, that is the overall advantage currently what is happening that, the tracer particle down to 100 micrometer particle you can use you cannot use a very small tracer particle because you have to reradiate it, make it a gamma positron emission source. So, generally the particle in the 100 micrometer range is being used, you can locate the particle within 1 m m range and 1 micro millisecond time.

So, that is the maximum temporal resolution you can get and maximum spatial resolution you can get, definitely this resolutions spatial resolution and temporal resolutions are lower compared to the PIV and LDA the experiments, but major advantage of this is that it can major the flow in a opaque system of very dense system or where the discrete phase system discrete phase fraction is very high. That is the major advantage the another major advantage and that is the advantage over the radioactive particle tracking technique and the other technique is that no calibration is required.

So, just like LDA here or PIV here again you do not require any calibration and that is the major benefit because we have the system which is opaque, you have the system where the discrete phase fraction is very high. So, the calibration is the very challenging in this case and we will discuss that how challenging the calibration is and as I mentioned earlier the technique, wherever you have any required a calibration the accuracy of measurement will be limited to the accuracy of calibration. So, these things can be neglected you do not require any calibration and that is the major advantage of the PEPT over the RPT.

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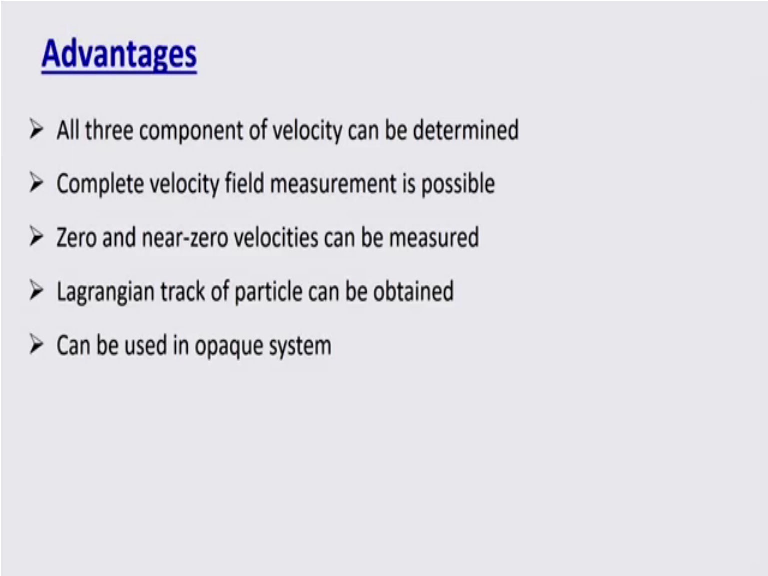

So, the advantage which I will say is the basically again it can measure all the three component of the velocity with the direction, it can map the complete velocity field even in the PIV if you want to measure the complete column if the column size is big, you cannot do it you can focus to a certain area because that will be the only focal length available with the camera, you cannot go beyond it, but in PEPT you can major the complete flow field.

The problem is you are tracking only one particle at a time. So, it will require a huge time to complete the experiments, but you can ideally track the complete flow field you can major you can major very low velocity, you can measure a very high velocity, but the only thing is you can have to see you will be limited with the temporal resolution and spatial resolution.

So, you should not be limited with that its a very high velocity your temporal resolution should be higher. So, that you can catch the each movement, you can catch lot of d you can have the data in either the particle will move a very far distance before between the two subsequent data acquisition time; so, temporal resolution need to be improved. So, within that temporal resolution, you can acquire the data at a very high velocity. For very low velocity also you can use the only thing is you have to be taken care that between the two subsequent time or two subsequent data acquisition, the particles should move certain distance which can be detectable ok.

So, that should be higher that one need to be do the major thing is you did huge data set and again we will discuss the importance of this data set while discussing the RPT, you can get the Lagrangian track of the particle, individual particle that how the particle motion is changing and major is as we already said that it can be used for opaque system with the other two non-invasive technique with which we have discussed cannot be used.

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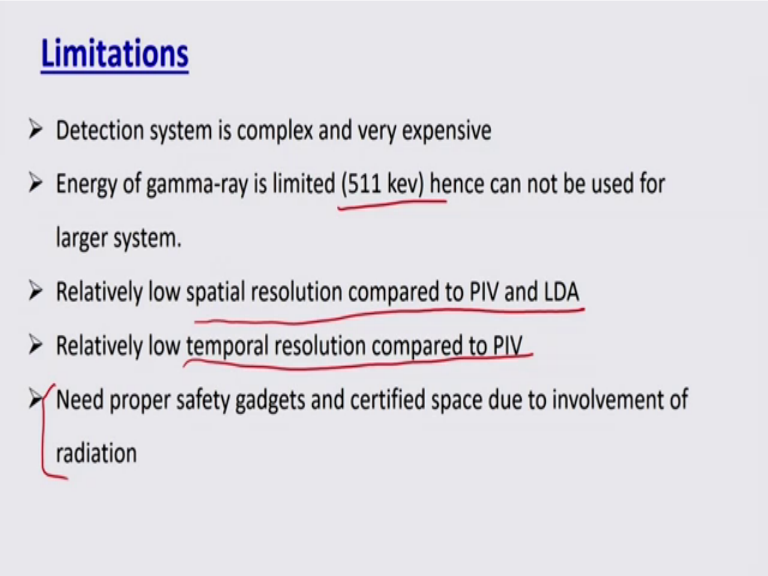

The disadvantage the detector system is very complex, its a array of the detectors the simultaneous detection is required. So, this is kind of a very complex detection system and that is made the cost of peptides very high very very high actually and we will see in comparison to RPT, this cost at least will be order of magnitude higher, but its very very costly compared to RPT which will discuss next.

The next limitation is that because you are generating you are not using the gamma ray source, you are using a source which is generating the gamma rays because of the annihilation, the energy of gamma ray is fixed to 511 K e V and therefore, for a very big system or the system where the wall thickness is very high or internal thickness are very high, you cannot use it your attenuation will be very high. So, your signal to noise ratio will be very low.

So, therefore, that limits the application of this to not a very big system suppose if I have one meter diameter or so, the system accuracy will be hampered or system accuracy will be compromised ok. It has relatively lower spatial resolution compared to PIV and LDA as I said that resolution goes in order of 1 m m. So, it is much lower compared to the PIV and LDA which claims, it has relatively low temporal resolution compared to PIV particularly once you are using a high speed camera or the two pulse mode where the pulse between time between the two pulse can be in the order of nanoseconds. And major disadvantages again is you need proper safety gadgets you need a TLD badges you need proper dosimeter you need areas survey meter to monitor the radiation label around you because you are dealing with the radiation.

Then second thing you cannot use this technique everywhere, you need to have a proper certification you have to acquire the proper approval from the concerned authority, in India that authority is atomic energy regulatory board, you have to get the certification from them that your laboratory is safe enough to use the radiation, you have to specify to certify the lab.

So, this is again the limitation is not like TLD and LDA that anyone can use you require lot of homework, lot of work before you start doing these experiments.

So, lot of approval will be needed you need a trained person who knows how to handle the radiation and all. But major advantage which give the boost to this technique is that you can use this technique for opaque system, you can use this technique for opaque column.

So, if the column is opaque you can use it, if column is transparent, but system is opaque like the fluidized bed I shown the previous diagram figure you can still use it because you are using gamma radiation. So, it can penetrate anything that is the major advantage over it ok.

So, next class whatever we are going to discuss, we will discuss about the radioactive particle tracking technique, and whatever the reconstruction approach a post processing approach we will use we can use it here. Only the reconstruction of the particle here is generally done with the triangulation theory. We will discuss the different reconstruction has got some there, but most of the post processing approach can be used for the PEPT also.

Thank you.