

Advanced Measurement Techniques in Fluid Mechanics and Heat Transfer

Prof. Saptarshi Basu

Department of Mechanical Engineering

Indian Institute of Science, Bengaluru

Week – 08

Lecture - 38

Micro PIV – 1

Hello everyone, we will be talking about the micro PIV technique, and we will discuss the basic principles of PIV and the micro PIV technique, how it varies with the PTV technique (particle tracking velocimetry), and the issues related to such systems, as well as how to troubleshoot some general problems. So basically, the overall idea is to give an overview of this technique. So why do we actually need a technique that helps us visualize any kind of flow? What I mean to say is that you have air all around you, and you also deal with water everywhere, but we cannot see it. So basically, if I am saying something, I am blowing a lot of air around me, but how do we visualize that as fluid dynamics? We are very concerned with the fluid properties and how the forces and similar factors play a role in changing their structures and properties. So that is why we want techniques that can help us find various flow parameters like pressure, temperature, and those kinds of things. So basically, I will show you some videos where you can see how we visualize air.

So here you can see we are blowing an air jet, and you can see we are able to visualize this jet very well, and you can see the flow around it also, which is actually getting sucked in because of this high-velocity jet. Now we are using olive oil droplets of almost micron size to visualize this. However, we are also illuminating it with a green laser light, which is a very high-power and high-intensity source of light. Now, once we turn off this light and do not see the air with olive oil droplets, we will also be able to generate these jets—high-speed jets and low-speed jets—but we will not be able to see them.

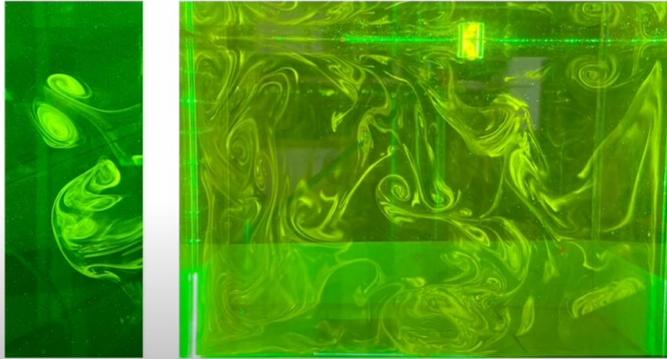
Introduction



Air jet seeded with olive oil droplets



Underwater visualization



So it is very important to seed it and those kinds of things. So for this, this is just a trial video, and using this video, you can actually extract the characteristics of such kinds of flows. And inside the water, I will show you some more images. Here, you can see some underwater visualizations. of nothing but the water.

So, what we did was take some rhodamine, which is a fluorescent material, and we basically made the laser light fall on it, and you can see these standing structures of vortices, which are actually underwater. So basically, this is a tank, and everything is happening inside this tank; and mind you, this is at very low time scales. So basically, these are standing structures that actually keep forming inside any kind of water pool. So, visualizing this is really important for us as engineers and as fluid engineers, basically. And so, PIB is one of those techniques that actually helps us visualize as well as extract quantifiable data from that visualization, which can be used to calculate a lot of things.

Determining the velocity of fluids, as we saw, is not as straightforward as that of solids because with solids, you can very easily track a solid, and at large scales, basically, if you have a ball of 1 cm, or say 10 cm or 20 cm size, you can easily see it, visualize it, and reveal the velocity in many ways. However, this is not the case with fluids because by fluids, I mean gases and liquids, as we cannot actually distinguish the molecules very easily with our naked eyes. So, we need some techniques. So, there are a lot of techniques; a few of the indirect techniques for measuring the velocity of fluids are pressure probes, anemometers, hot wires, etc. Pressure probes are widely used.

Introduction



- Determining the velocity of fluids is not as straight forward as solids since, here there are no visible objects that can reveal its velocity.
- There are few indirect techniques like using pressure probes, anemometers, hot wire, etc.
- Although, cheaper, they can lead to large measurement errors as they are mostly intrusive in nature and provide data for a single location.
- Optical techniques like PIV, PTV etc. although being costly, can give more accurate and comprehensive results for the flow field.
- They are mostly non-intrusive in nature.

These are mostly based on Bernoulli's principle. However, they are cheaper. They can lead to large measurement errors because most of them are actually intrusive in nature. So, what I mean by intrusive here is that you have a flow field, and then you have to put something inside that flow field at a single point, and that will respond to the changes in the fluid that are happening using some kind of signal, and it will generate some kind of signals, and those signals will then be used by you or us to get the quantifiable data. So basically, one of the other problems is that it is only giving you velocities or other parameters at a single location, which is mostly not desirable for us.

Now optical techniques like what we are talking about, such as PIV and PTV, are very costly but can give you very accurate results and also provide a comprehensive result of the flow field. Basically, if you have a flow inside a channel, using an optical technique like the laser, which I showed you initially, it actually illuminates the whole region from which you can extract data now, unlike the other indirect techniques. And as said, I mean, these PIV and PTV are mostly non-intrusive in nature, well, at least compared to the other techniques. So, micro PIV stands for micro particle image velocimetry, and the idea of micro PIV actually comes from the macro PIVs, which you have already been introduced to in the previous lectures by Professor Basu. So, basically, the main idea and intuition behind the whole technique remain quite similar, other than the fact that now we are dealing with very small systems that are of micron size, and here the problems are pretty unique compared to the problems we faced during macro PIV systems, where the systems are mostly at larger scales and the setup, which is basically the usage of a camera, lenses, and a laser.

becomes a bit different in case of micro PIV compared to what how it is setup in micro PIV. However, again, the basic idea of finding the flow field remains that finding a quantifiable full flow field is pretty similar. So now let us see why we actually perform

PIV, as discussed in detail in the previous slides. Basically, we need to find the velocity field of different kinds of flow configurations, and that is why we do PIV. When the same is done for microscale geometries, we name it micro PIV—simple as that.

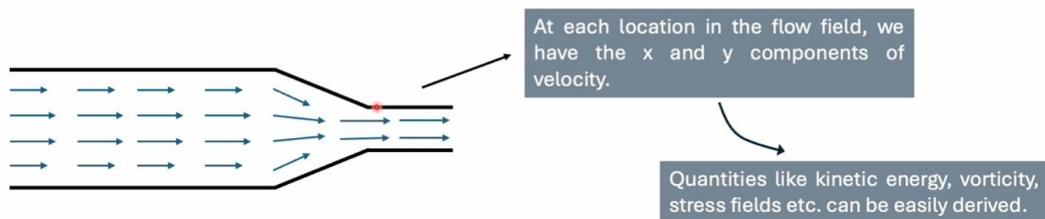
Introduction – Micro PIV



- Micro PIV – Micro Particle Image Velocimetry
- The idea of Micro PIV comes from Macro PIV

Why do we perform PIV?

- To obtain the velocity field different kinds of flow configurations.
- When the same is done for micro scale geometries, it is called as Micro PIV.



So, now here you can see there is a channel, and inside that, you see some vectors. So, this is basically a typical PIV output, you can say. So, suppose you have this channel which is of micron size you can imagine and now you have serrated particles and when you image it and do the micro PIV process you get something like this. Now, what are these? You can see a very regularly spaced vector, which are obviously velocity vectors, and you have resolved this whole section using four vectors. And then again here you can see they are converging, and then you see two vectors resolving this region.

So, basically, this is what you get from the output of the PIV. So, here you have basically at each location in the flow field, this channel has the x and y components of the velocities. For instance, if you talk about this vector here, you do not see any y component. So, they just have a straight vector in the x direction. However, here you can see this vector starts to incline in this direction.

So, you have some x component, and you also have some y component. So, if you decompose this vector, you will get two velocities. And again, here you see something very straight. So, now you have the velocity data of this flow field. So, now you have everything; basically, using this velocity data, you can find quantities of need like kinetic energy, vorticity fields, which are very important, normally stress fields, and also the pressure field can be derived using the velocity fields by putting it in the Navier-Stokes equation.

So, basically, if you have the velocity field, you have everything, and that is what we need from PIV data. So, here you can see a micro PIV setup from LaVision at our lab. So I will just briefly go through the components, and we will be discussing them in a bit more detail in the later slides. So here you can see this grey box is the PIV laser and this laser actually comes through this attachment and it comes inside here. And basically, this is a dichroic mirror, and this laser actually gets reflected and goes back on top.

Introduction – Micro PIV

- Micro PIV – Micro Particle Image Velocimetry



Now, what we have on top is basically here; you will have a microscopic objective, and this is the sample which you want to visualize. Here, you can see a small spot, and that is basically a droplet, and it has some fluorescent particles inside it. Now, when this laser actually comes here and goes up, these fluorescent particles will emit. Light of the required wavelength is basically whatever it is made to do. So, here, if it is a green light, it actually emits red light, and basically it comes here, and because it is a dichroic mirror, it will actually reflect back, and there is an arrangement that actually reflects that emitted light at this angle, this side, and you have a camera setup here.

So, for your information, these kinds of setups are highly modifiable in nature, and you can change the camera, you can change the laser, and you can actually make it an inverted microscope as a whole. So, yeah, here we are using an imager intensifier, as you can see, which is suitable for capturing low-light images. It actually converts low-level light to electrons and amplifies those electrons to get better images, but normally high-speed cameras are used and those kinds of things. And then you can actually put a microchannel here, and you can make the flow inside that, and you can record things from the bottom. So, let us talk about the basic idea behind particle image philosophy in general.

So basically, to visualize any kind of fluid, it can be either a gas or a liquid. We use some kind of cedar particles, also known as tracer particles. We put it inside those fluids, and basically, we assume that all the tracer particles follow the fluid faithfully, along with that cedar particle. So this faithful term signifies that the particle would not behave differently and should actually respond immediately to whatever changes are happening in that fluid. So the use of cedar particle is the most important thing because that helps you visualize and the choice of cedar particle is probably the most crucial step in doing PIV.

Introduction – Micro PIV



Basic idea behind PIV?

- Use of seeder or tracer particles to visualize fluid flow (can be gaseous or liquid both)
- Using images recorded at different time intervals, the displacement of a group of particles in a region is calculated
- This displacement is used to obtain the x and y components of velocity.

But how is it different from PTV?

PTV – Particle Tracking Velocimetry.

Now what we do is use images; we record images at different intervals of time, and then the displacement of a group of particles is calculated using some kind of correlation. So, we will talk about that in the later slides. And this Δt , basically the different time intervals, can actually be set according to the time scales of your experiment. And then, the displacement is used to calculate the x and y components of the velocity. And as already said, I mean, if you have the x and y velocities with you, you can find almost everything in a flow field that is needed.

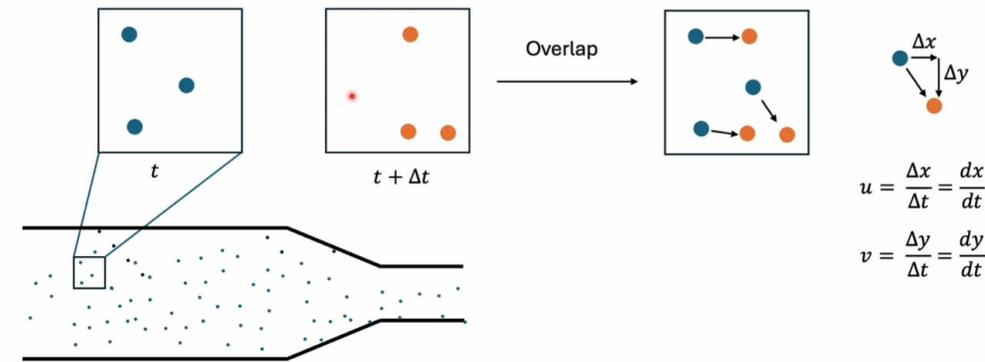
But again, how is it different from PTV, which stands for particle tracking velocimetry? So now we will briefly go into PTV. We will talk about this technique as well because it is kind of an old-school technique, but it is very intuitive; if you see some particles inside a flow field, your first intuition would tell you to track that particle. So, this is what PTV actually does. So, that is why I will just go through it, and it should not be confused with PIV. So, in PTV, we actually track individual particles in the flow field.

Introduction – Micro PIV



PTV – Particle Tracking Velocimetry.

- In PTV, we track individual particles...



So, as you can imagine, I mean if you have a channel, you put some particles inside that channel and now you try to track those particles. However, again, this particle should not behave on its own. I mean it should actually faithfully follow the flow; only then will it be able to give you accurate data of the flow. So, what you do is basically take single particles, as seen here, and actually start tracking them over time. So, for representative purposes, I will show you; now let us talk about these three particles.

I mean you can also take a single particle in a window. There is no window as such, but just for representative purposes, I have shown it. Now, these three windows look something like this at time t . After some Δt , they have moved to a new position inside this window.

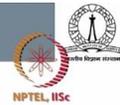
Let us talk about this window. But again, in practice, you do not normally need to use such windows at all for PTV. Now, if you overlap these two windows, you get something like this. Given the fact that these particles do not go out of the window, do not consider that for now. So, now you can see this particle has moved here, this one has come here, and this one has come to this side. So, now you know the Δt for the time it has come.

So, if you consider this particle, you can see it has moved Δx and then it has come Δy . If you resolve basically this vector, you get Δx and Δy , and then in the u direction, you can say the velocity is basically $\frac{\partial x}{\partial t}$, which can be approximated as dx/dt . And also in the y direction, you can get $\frac{\partial y}{\partial t}$, which is dy/dt . So, basically, what you are doing is picking up each particle and tracking it over time. So, this Δt is very important, and it should not be very large because if it is very large, then you capture these two images at very far time intervals.

Basically, if there is some kind of gradient in the flow or some kind of turbulence, then the particle might get lost during that Δt . So, this Δt needs to be chosen very carefully depending on the type of flow you are dealing with. So, let us see what the common issues associated with PTV are. First, many times these particles can actually become indistinguishable if they are in excess in number. So, basically it is very important to have a very small number of particles in the flow field, and also if you use a large amount of particles, I mean this large term is very relative because it depends on the channel size.

So, if you are using a large amount of particles compared to what the width order is, like basically what the volume of your microchannel is, it can actually clog it, and that can definitely disrupt fluid flow because if it clogs your inlet or outlet, there can be high levels of pressure drops, which can actually cause a lot of fluctuations and those kinds of things inside your microchannel. So yeah, PTV is very important to keep this in mind. And again, one of the major problems is that it is very tough to get regularly spaced vectors as in the case of PIV because your particles will also be fewer in number. So, you cannot get vectors in every place because the particles are very sparsely arranged. So, mostly PTV is very desirable when you deal with it.

Introduction – Micro PIV



PTV – Particle Tracking Velocimetry

Issues:

- Particles can become indistinguishable many times if they are in excess in number.
- Usage of large amount of particle can clog micron sized channels and may disrupt fluid flow
- It is tough to get regularly spaced vectors as in case of PIV

Live organisms, like bacteria, or at those scales where you are actually tracking a single cell rather than finding the flow field of a system, like flow inside a channel or basically flow inside a microchannel, and those kinds of things. So, this technique is normally used when you are actually tracking the motion of bacteria or other kinds of organisms. I will briefly talk about the PTV algorithm, not exactly the algorithm but some of the scenarios we face while basically doing PTV. So, PTV depends heavily on the method of imaging. So, basically, different images and different types of imaging can have different intensity profiles across the particles, and the variation of intensity can be very low or high, and there can be a lot of noise in the image.

So, it's very important to know the intensity variation in your imaging system. Okay, so now let's see some scenarios: you have a particle here. This blue color actually shows the intensity of the particle, and it can be tracked in the flow field outside here; now you can see that the intensity inside the particle and outside the particle remains very similar, just that the edges can be seen to be very dark. Let us see that this is I_1 intensity, and inside is also I_2 , and these two are basically the same. Now, if you actually draw a line across the center of the particle and plot the intensity across that line, you will get something like this.

Basically, you are getting these two peaks, and these two peaks are actually the two edges where the line is cutting the particle. Now, if I talk about this, it is something like this. Basically, if you have this line here, these two peaks actually correspond to this part and this part. Now, if there are some noises, which is normally the case, actually, the intensity will look something like this; it will vary here. Also, I am not making it, and here, and again, this.

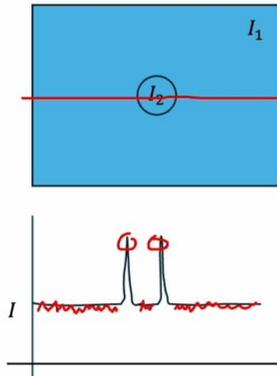
So, now what do you need to do? What you need to do is basically locate the edges using these peaks, and then you perform some edge detection algorithm. And then, if you have the two edges, you can actually fit a circle around it and find the center of the circle. This can actually have some variation, but this kind of scenario is mostly rare, and you do not encounter it often. So, normally we deal with this kind of system where it is a fluorescent imaging technique, where these particles are very bright, and outside you get a dark field, basically, and now for this case, if you actually again draw something like this.

So you actually get something. The intensity profile looks something like this: it's very smooth, and you can use a Gaussian fit; basically, if it's an ideal fit, then the center of this should give you the brightest intensity. The pixel at the center should give you the brightest intensity, and you can actually get the center of the particle from this graph, right? And then you can trace this brightest pixel along the flow fit. So, these are the techniques, and there are other techniques like the centroid method, the intensity weighted centroid, area weighted centroid, and those kinds of things that you can actually use to track particles in PTV.

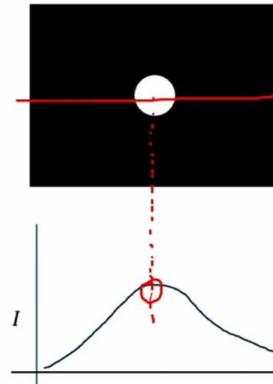
Introduction – Micro PIV



PTV – Particle Tracking Velocimetry algorithm



So, locate the edge, performing edge detection, fit a circle and then estimate the center to track



Trace the brightest pixel and that should lie at the center of the particle