Two phase flow and heat transfer

Dr. Arup Kumar Das
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture No: 11
Measurement of Void Fraction and Signal Analysis: Part-02

Hello welcome in the eleventh lecture of Two Phase Flow and Heat Transfer. Today we will be discussing the second part of measurement of Two Phase Flow and signal analysis. In the previous part we have discussed about conductivity probe, electrical conductivity probe and optical probe. Here we will be continuing from there majority of the portion of this lecture.

I will be covering for multi sensors for multi probe and the signal analysis of multiple probes okay. Okay as the outline of this lecture I will be speaking that in this lecture we will be highlighting the essence of signal analysis first.

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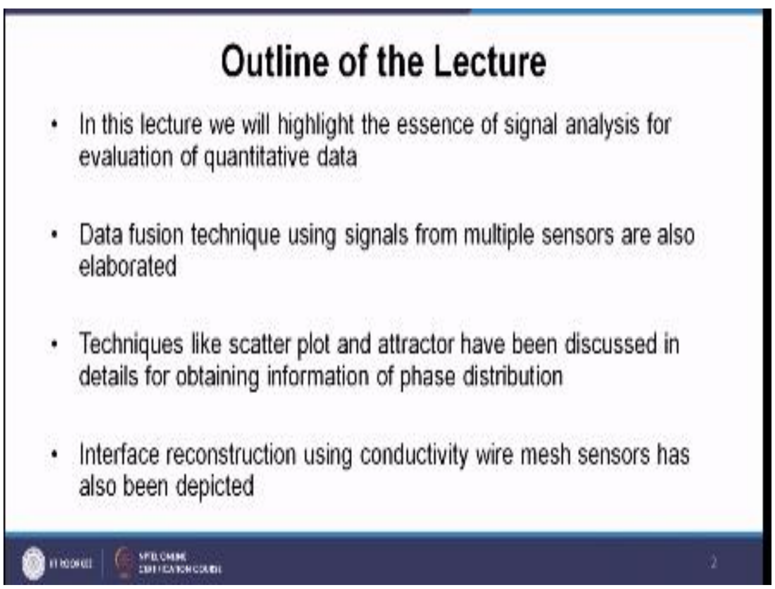

In the previous lecture we have shown you signal analysis but today in this lecture I will be first giving you what is the essence of that one and how features can be obtained from the signals. So the essence of signal analysis for evaluation of quantitative data will be explained. Next we will be showing you using multiple signals from the sensors how data fusion can be done and you know quantitative information can be obtained okay.

For that I will be showing a information from some statistical features and some neural network. Also I will be discussing about modern techniques for signal analysis like scatter plot, attractor okay time delay plot and so on okay. I will be also showing you that how using multiple sensor data in 1 array I can reconstruct the interface. This is for you know highly well defined interface. So I will be showing that technique also okay.

Now to begin with, first I will be showing what is the essence of all the signal analysis or you can say that transforms from the signal. So I will be showing you what is signal transform okay. Now signal transform for signals we will be considering the signal as some sort of output of a probe which is changing with respect to time. So we are having variations in time domain okay.

So let us the time is progressing in 1dimension and there will be variation in the signal in the other direction okay. So it can be voltage, it can be current, it can be flow rate or any other data which is varying with time okay. Now using transform what we can do using transform, we find out what is the typical feature of that time domain variations and what are the dominant frequencies and what are the dominant modes of that signal whatever we have obtained from the probes okay.

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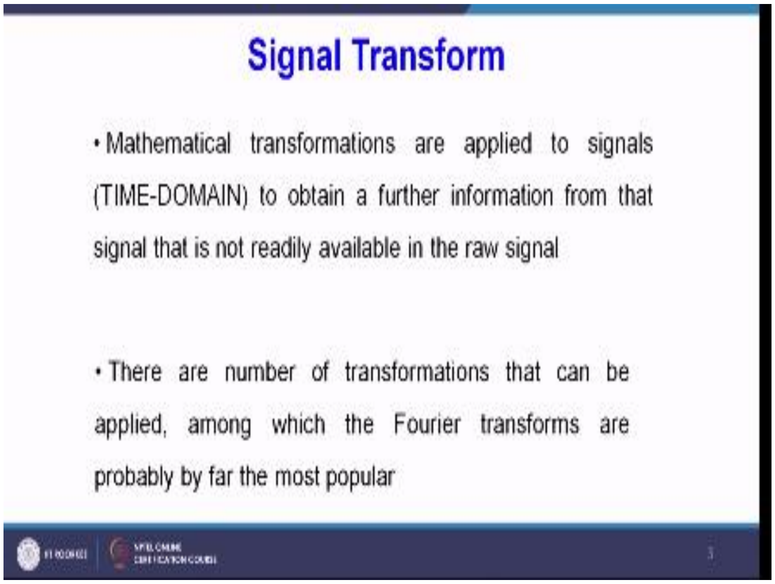

So typical signal transforms are Fourier transform which I have shown you in the previous lecture also. Fast Fourier transform and here also we will be showing you some new signal analysis techniques. So essentially signal transform is required from a time dependant data and obtained the important feature from there okay. Next I will be showing you over here 1signal.

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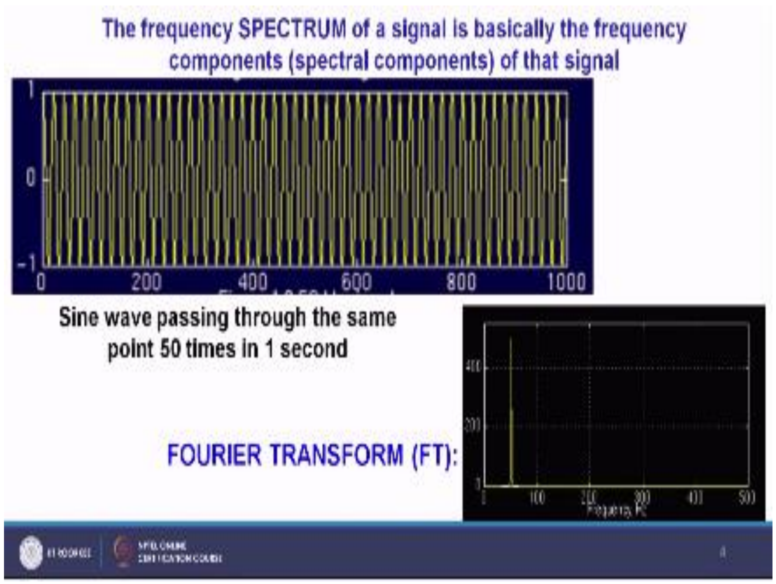

You see basically here in this plot you can find out this is time okay. And here we are having some data and this may be some probe signal, optical or electrical conductivity probe or some other type of probe signal. So here let us consider that we are getting the signal. What I have shown you over here, this is actually a sine wave you can see it is showing sinuous nature okay.

Moving up and down so sine wave passing through the same point okay, 50 times in 1 second. So here you will be finding out this is having frequency of something around 50 okay. So this I have shown and once you go the Fast Fourier transform for this signal, you will be finding out this is the Fast Fourier data of the signal okay.

I will not be going into mathematical detail of Fast Fourier transform because that is the part of mathematics but I believe that all of you know that how to do Fast Fourier transform of time dependant data. And if you do that when you will be finding out that this is the FFt of the signal and you can find out peak, sharp peak just at 50 times okay. So whatever, signal we have given over here 50 times in a second so that came out over here as the peak in the Fast Fourier transform.

So once we have some time dependant data and we find out it is Fast Fourier transform, it will be giving us the dominant peak okay where it is characteristics lies in okay. Next, to elaborate this further what I have done, I have added few more sine wave curves over here rather cosine curves over here.

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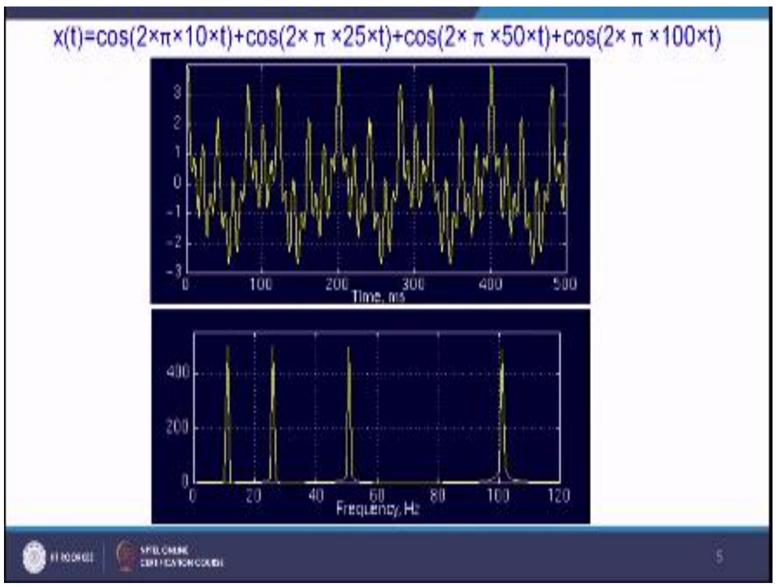

So first 1, you see what we have done cos of 2 pi 10 t. So the frequency is 10. In a similar fashion then + cos of 25 t, cos 50 t and something cos of 100 t. That means this xt which is varying with time this can be voltage also is having actually summation of 4 cosine curves okay. If I see the raw signal, so this is the time axis and here we are having the x okay which is varying with time you find out this erratic nature.

But if you see minutely there is some short of periodicity in this signal and you can find out these are constructed by actually 4 amplitudes okay. So this 10, 25, 50 and 100 will be coming into picture. Though this is you can observe this 1 minutely, once you see in a close look. But what we can do quickly we can go for Fast Fourier transform of the signal and find out what are the dominant frequencies.

So over here you can see, I have shown the Fast Fourier transform of the signal and interestingly you can note that we have got a peak at 10. We have got another peak at 25; we have got the third peak at 50 and finally the fourth peak as 100. So you see whatever we have given 10, 25, 50 and 100 that has actually obtained back.

So that means if you are having some unknown signal like this and if you go for Fast Fourier transform, immediately you can find out where you are having the frequency peaking okay. Now, 1 interesting thing about these two plots okay. Time domain plot, this one as well as this one is that here in these 2 time domain plots. We have taken data at same interval that means t2 -t1= t3 -t2 and so on.

So that means the (()) 07:16 sensor is giving you signal at a same frequency that means sampling rate is same okay. So almost it is giving at a same rate. But some point or in some measurement device you can find out that this rate is changing okay. So you are having variable time. The sensor is taking variable time to acquire the signal and send it to the computer.

So let us see another signal, this so here you can see that signal raw signal with different frequency. So you see over here this is a time domain and here this is some signal, let us say voltage.

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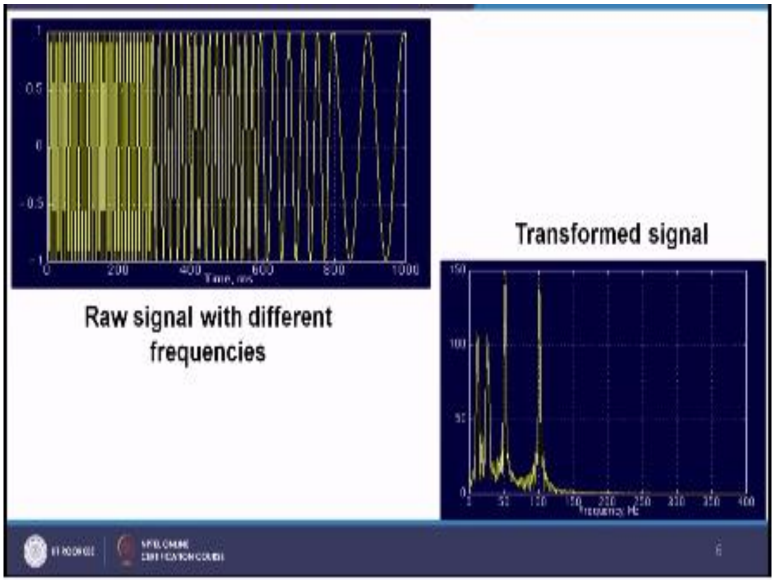

So here you can find out these are very closely spaced. So that means here a very fast signal obtained and here the sensor may be is not functioning properly or taking some time due to the phenomena and you will be finding out this taking more time to give you 1 signal. So if you see this type of situation say in your raw signal then also we can find out the characteristic features of this type of signal using FFt.

So you see what we have done, we have transformed that signal into FFt car. We can find out some pix also are coming like this. So from by comparing this 1 and your previous signal, you see here you have got a sharp peek at 50 but here what we have got, we have got a peek at 50 but subsidiary peeks are also obtain that 100 and here we are seeing something around 25, 20 something like that.

So this gives you some sort of idea that at which rate the signals are actually taking a time to give the readings to the output okay. So these are the ways how we can find out some of the quantitative data from the signals. Okay, next I will be quickly moving to different techniques. So first I will be showing you data fusion okay.

How using a multiple sensor using data fusion you can find out quantitative signals. So here I will be using a typical flow called core annular flow.

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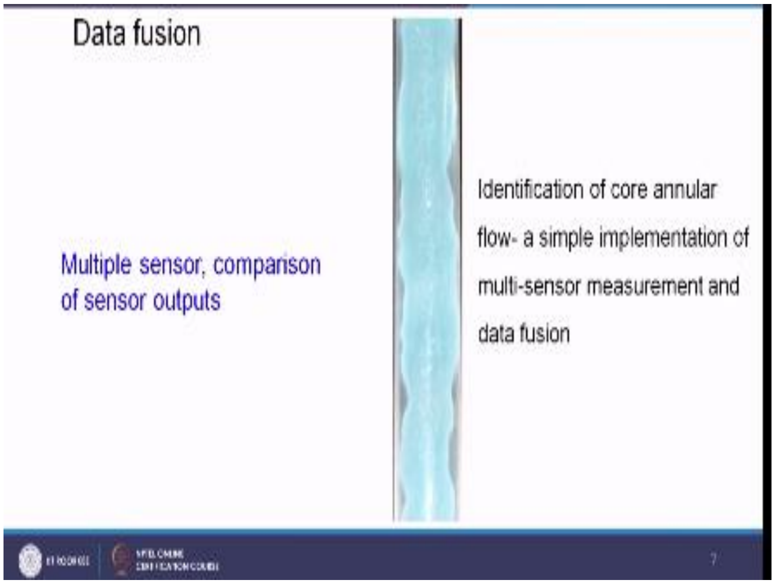

So this is actually liquid liquid core annular flow, a figure I have shown you over here this is the kerosene figure okay kerosene and air. In the annular domain, you see here we are having the white portions these are actually water. So, this is liquid core annular flow and the liquid, liquid pale is kerosene and water. So, let us try to see that whether we can capture this annular flow using, you know multiple sensors and if you compare the signals between the sensors okay.

So what we have done, find out this one we have taken the help of conductivity probe but we have taken the help of multiple probes over here. So let me first explained that what type of probes one can consider. So first one is that these are called wall mounted probe.

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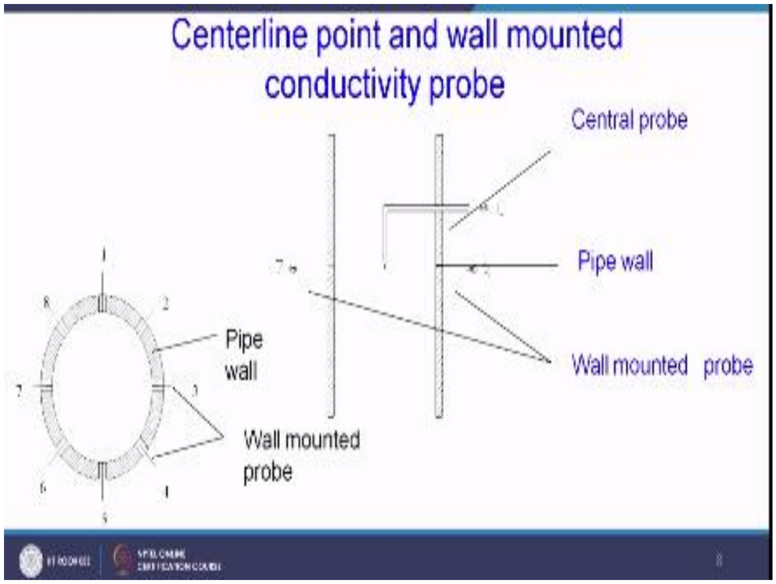

So this is the cross section of the pipeline so you see what one can do, they can make through hole in the pipeline and you know they can flush this wire this, all these numbered line for actually wires those wires are actually your electrodes okay. So active electrodes and those are entered in the holes are come from particular angular sectors.

So you see here, we are here given 1, 2, 3, 4, 5, 6, 7, 8 sectors and those are entered. Now all these are wall flushed. Flushed means nothing we will extend inside the wall to restrict the flow. So there were actually just ending at the wall inside boundary okay. So, all these are once again connected to the circuitry.

The circuitry already here have shown in the previous lecture. If you remember those will be oscillator and then we are having WHEAT STONE BRIDGE finally RECTIFIER and then FILTERS so anything for there. So, all these probes will be going to the signal conditioning meets part from this wall mounted probe. We have also given a central probe so this frontal view of the Pipe.

Let see so wall mounted probes you can see over here. So this view we have taken along this surface. So this is axis so we have seen 7, 3 axis okay. So you can see the 7 and 3 okay and there will be 1 central probe okay which is actually penetrating the tube and coming in the flow and restricting the flow path also to some extent. So that we have called a central pole and we have given that make 0. Now let us see these signals.

So what we have done, as we are having probation for taking all those 8 + 0, 9 signals. So we can use actually lots of combinations and parameters permutation. So what we have done over here, we have found out the probe signals here in this fashion.

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Measurements from wall mounted probe

Probe	Water (U_{SW}=0.3 m/s)	Kerosene (U_{SK}=0.4 m/s)	Water-kerosene (U_{SW}=0.3, U_{SK}=1.2 m/s)
	Average Volt	Average Volt	Average Volt
1-2	6.53	4.66	5.96
1-3	6.50	4.60	5.80
1-4	6.49	4.52	5.50
1-5	6.49	4.59	5.03
2-3	6.53	4.66	5.96
2-4	6.50	4.61	5.80
2-5	6.49	4.40	5.50
2-6	6.49	4.59	5.03
3-4	6.54	4.66	5.96
3-5	6.50	4.60	5.80
3-6	6.49	4.40	5.50
3-7	6.49	4.59	5.03

So first is 1 and 2 in between 1 and 2. Already I have shown 1 and 2. So, the signal between 1 and 2. So what is the signal difference between 1 and 2 we have shown over here? So you can find out that we have shown here 3 different conditions water, kerosene and water kerosene. So water kerosene will give equal laminar situations okay.

The flow rate are taken such a fashion that will be giving you laminar situation by the way these flow rates are once again insulated flow line map whatever I have shown in the second lecture. Now if we are having flow water inside the pipeline, so you can find out all these combinations are giving you to something around 6.5 okay. All the voltages are in the range of 6.5 okay.

You will see we are having if you are having kerosene okay then you can find out it is something in the range of 4.56 something in that rate range. Now interestingly what we have found out, whenever we are having both in the form of a core laminar pattern. So you see it is coming something around in between these 2 okay. Though you see in the wall, all these are wall mounted flow.

You see 1, 2 no where we have featured 0. So all these are wall mounted flow. So though all the probes are actually connected with the wall interface because we know in the case of core annular flow obviously will be having the water added with the wall but still you see the signal whatever we have obtain that is not equivalent to the water signal. This is lying somewhere in between.

So what we can do essentially using this type of signals. We can predict back that whether you are having core annular flow or not inside the pipeline. Let us go further and see that there are fusion techniques. So here you see I have shown you some signals of the wall mounted probe and the centerline probe also okay. So you see all these are with 0.

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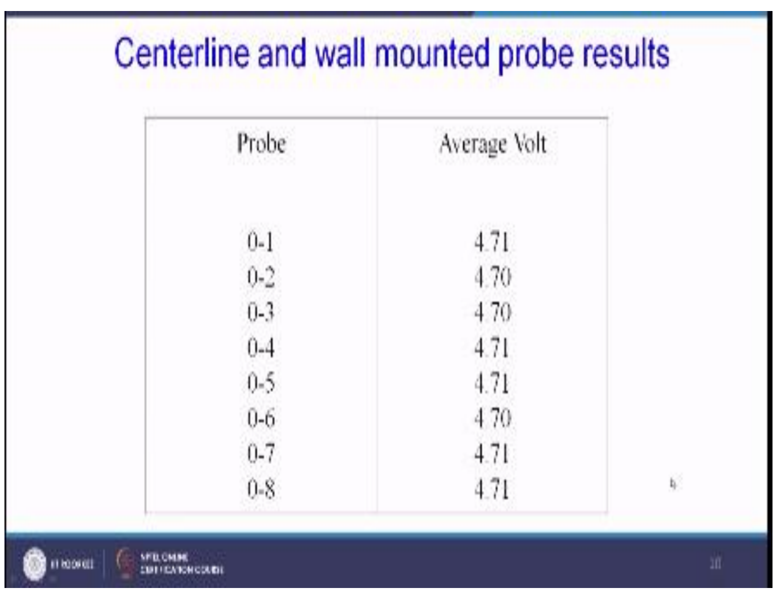
Centerline and wall mounted probe results

Probe	Average Volt
0-1	4.71
0-2	4.70
0-3	4.70
0-4	4.71
0-5	4.71
0-6	4.70
0-7	4.71
0-8	4.71

So 0-1, 0-2 to 0-8. So see here the voltage will be coming in between 4.7 which is more near to the signal whatever we have obtained to the kerosene because you know the center probe and the wall mounted probe they are having contact between the kerosene and water also. Okay because at the core we have the kerosene. Now let us see depending on all the signals how I can identify the flow regime.

So what we have shown over here, here for data fusion we have shown few mores probes as I have mentioned in this previous slide. So apart from these probes wall mounted probes and central probes we have also given 2 diametrical probe which I have shown you in the previous lecture and some ring kind of wall probe like this.

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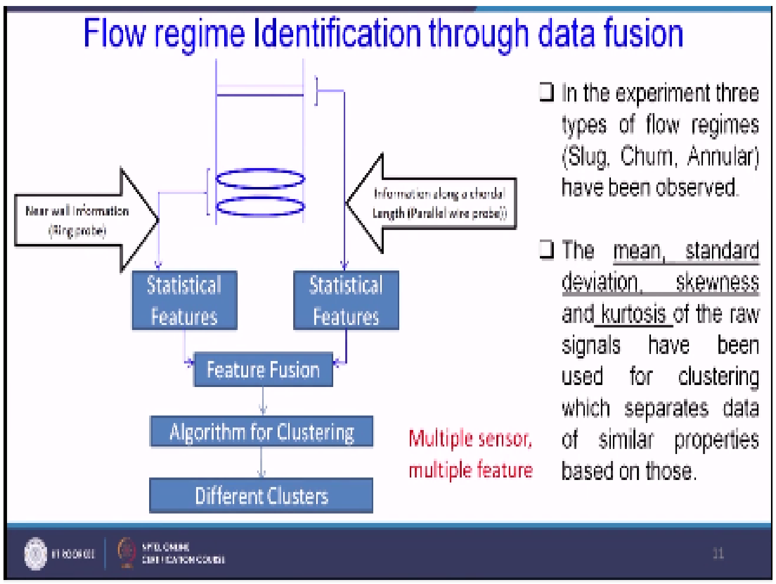

So ring kind of wall probe is nothing but a circular ring attached with the inner wall of the tube okay. So 2 rings we have given like then from there we have obtained the signal. And here these are actually diametrical wires. So these actually, these 2 wires are actually in 2 strip types so actually restricting flow path. But these are actually wall attached okay wall attached ring kind of probe so these are not restricting the flow path.

So what will be doing will be calling this 1 as a ring probe and will be calling these 2 as parallel wire probe okay. So what will be finding out using both the pears of the probe, will be finding out the statistical features okay. And then using this statistical features will be going for some fusion. Now what will be the fusion technique that is a matter of research and depending on the flow regime what flow regime you were starting, the technique of fusion will be varying okay.

And sometime it will be varying on the flow rates also. So here I am not going into the detail of the fusion technique. So what based, what technique is that you can go for some neural network fitting okay. Train the data using some of the signals okay and predict the flow regime and then later on that you can do for some unknown features and same fusion technique you can find out the flow regime happening inside the pipeline.

So here what we are doing initially. Both the features we are actually fusing over here so this is called future fusion. And then we go for some clustering. So what is clustering, so after fusion we will be finding out the fused data they are of in wide range? So then what we need to do, we need to clusterize similar type of signals okay. And then plot them.

So this is something called algorithm for clustering so and finding out the similar type of fused data and then finally different clusters will be plotting in different places. So what we do here, we have shown an example of multiple probes and multiple features also over here. So this is a statistical features from the ring probe and this is statistical feature from the parallel wire probe okay.

Let us see that how using this different clusters and algorithms we can find out different flow regimes are identify different flow regimes. So here I have shown you a flow regime map constructed based on the superficial velocities of air and water and we have only focused on only 3 patterns slug, churn and annular.

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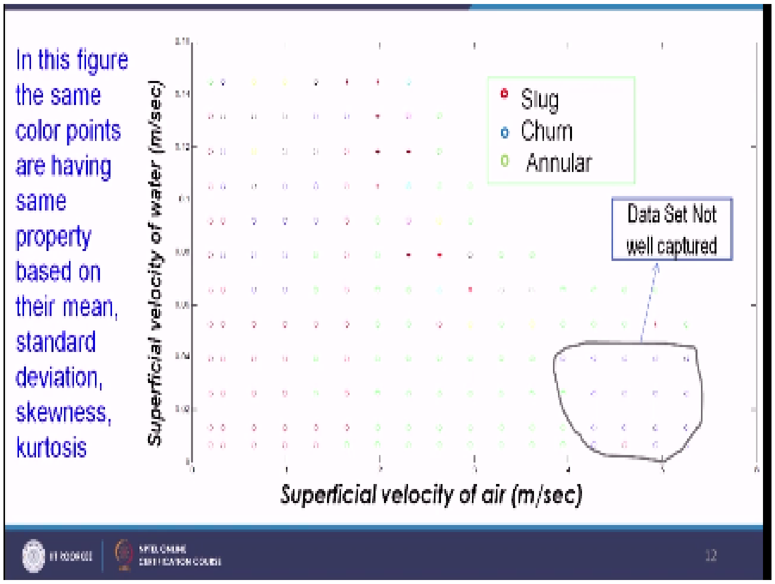

Now here all these points are identified based on the clusters as we have mentioned in the previous slide you say different clusters. So we have actually fused the signals obtained from this ring probe and parallel wire probe and finally we have found out 3 clusters cluster for slug flow, cluster for churn flow and then cluster for annular flow.

So you can find out over here we are having a very good cluster over here for the slug flow here you are having cluster, for the annular flow and finally here you are having cluster for churn flow. But there are some limitations on this type of techniques also. Some point at higher velocities will find out will not be coming into this cluster. So typical example is here you see mixed kind of pattern.

So but if you trade it well with a more number of data set points, you will find out that this type of technique will very helpful for flow regime identification. Next let us see new type of methodology where, you will be try to find out the oscillatory flow through an air lift loop, okay.

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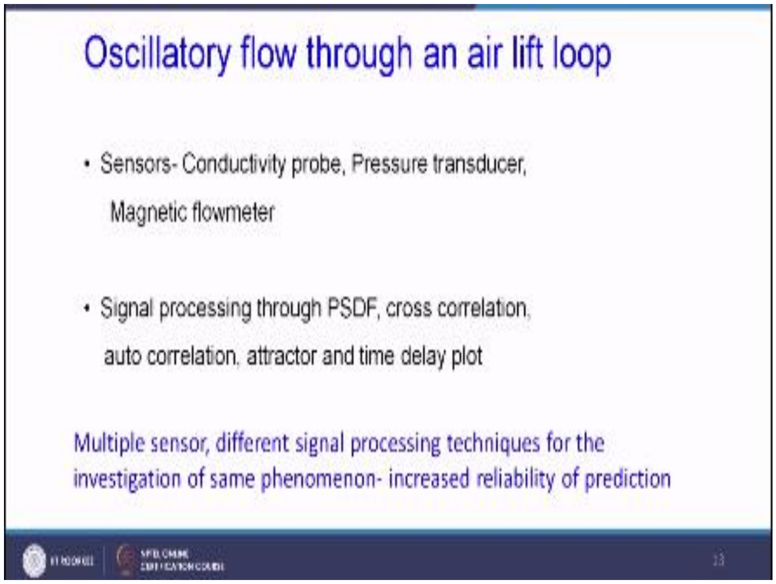

Here in this experiment you will be using conductivity probe signals pressure transducers and magnetic flow meters okay. And for signal processing you will be using PSDF, Probability Spectrum Density Function, cross correlation, auto correlation, attractor and time delay plot. So as we you have already understood this is having conductivity probes having multiple sensors over here.

And different signal process you will be elaborating in this. So this is a schematic of the set up as all of you know that air lift pump will be having 1 tank over here.

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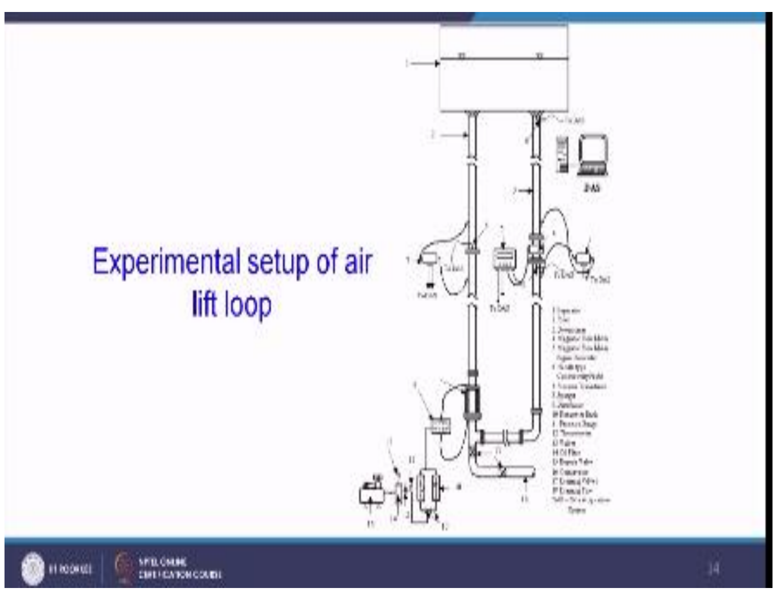

And we will be having 1 raiser, this is raiser and this is actually a down comer. So through which liquid comes down and from here it is once again moves up. Now in the down comer section what we have done, we have given the magnetic flow meters over her okay. Also we have given you have conductivity probe at 0.6 over here you see. And we have also given some pressure transducers in 0.7.

So you can find out that you are having all 3 types of measurements over here. Conductivity probe, magnetic flow meter and pressure transducers. So let us see how using these we can find out the regimes. Little bit details about the conductivity probe we have given over here which we have already discussed earlier.

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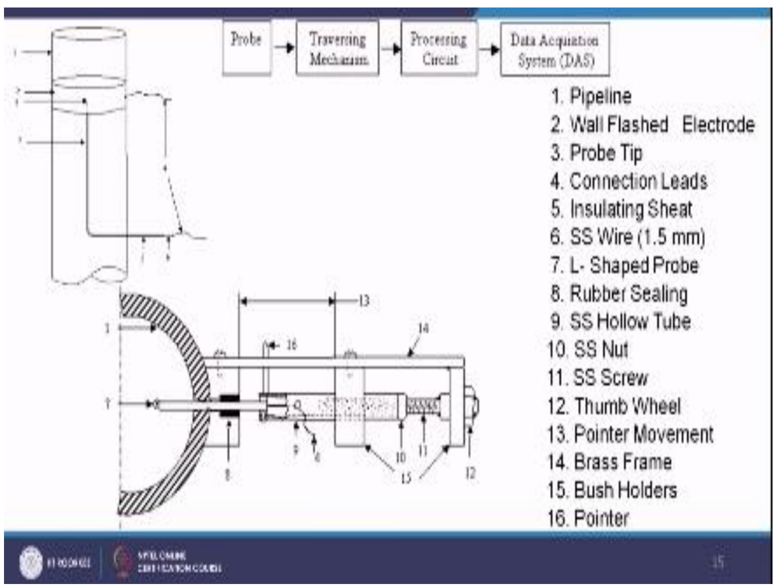

So this conductivity probe is having trade in type of active probe, also we are having a central probe which is kind of you know round so we will be taking signal between this ring type of probe and this central probe. And the cross sectional view we have shown over here. So this is your pipe section so along this we have a fused ring type of probe.

And this is your central probe, central probe can traverse along the pipeline that means go towards the center as well as it can come from periphery and we can have the signal between erring probe and the central probe. So this is a mechanical arrangement through which we can traverse a central probe towards the axis. Okay next let us see this technique whatever I have told you, we will be having a central probe.

So this central probe always gives you point based measurement.

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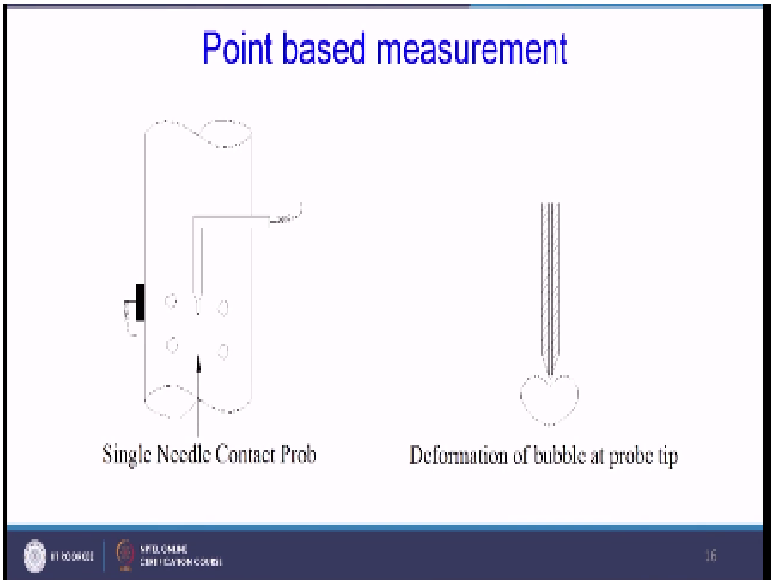

Why point based measurement because it will be sensing the flow of 2 phase at a single point. So this is a single point which is actually there, apart from that in this side we will be having electrically insulation. So you will be finding out that as it is point based measurement. It will be also involved in some sort of deformation of the bubble.

Let us say the bubble whenever it is moving up that may be spherical or some (()) 21:10 kind of thing. And whenever it is coming and contact with the probe that can you know deform in this fashion. So those errors will be coming into picture in this type of cases. Okay, now here I have shown you some typical signal if you find out over here.

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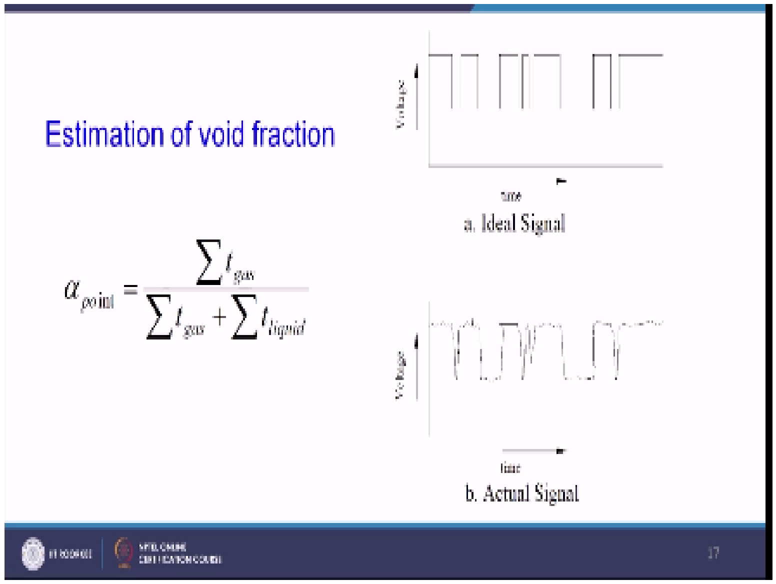

So you see this high voltage whatever we have obtained these are for liquid contact and low voltage whatever we have obtained for the gas contact. So if you try find out that how many times we have for this high voltage and how many times we have for the low voltage that will be coming as summation of t for the gas and summation of the liquid.

So your void fraction will be the summation of t gas / summation of t gas + summation of t liquid. So this is very, very idealized case we have talked about but in as it is point based measurement and I have told you the deformation actual car whatever will be finding out for voltage and time is like this okay. But once again you can little bit of filtering of this 1 and you can once again use this kind of analogy for finding out the void fraction.

Next let us see that how using this signals we can go for PSDF Probability Spectrum Density Function and we can evaluate the pattern of the 2 phase.

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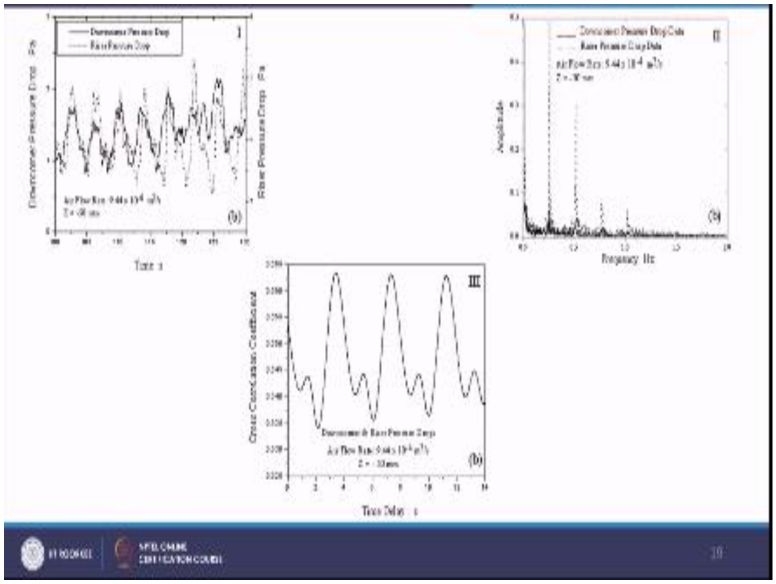

So here you see we have given you the raw signal with this respect to time this is actually down comer pressure drop signal from your pressure transducers. So you see we are having down comer and riser pressures over here which are very much erratic to see. Now if you go for the probability density function or let us say power spectrum density function of this 1 then you will be getting something like this.

It signifies high peak somewhere over here, peak somewhere over here and you see the nature of the primary peak and secondary peak is always having a falling nature right. So if you go for the cross correlation between the signals of the down comer and riser then you will be finding out cross correlation gives you something like this okay. So this is at very low air flow rid.

So air flow rid we have chosen here as 9.44 into the 10 power of -4 metric cube per second okay. Once you increase the flow rid, you see here it is almost double. So 18. 9 *10 to the power of -4.

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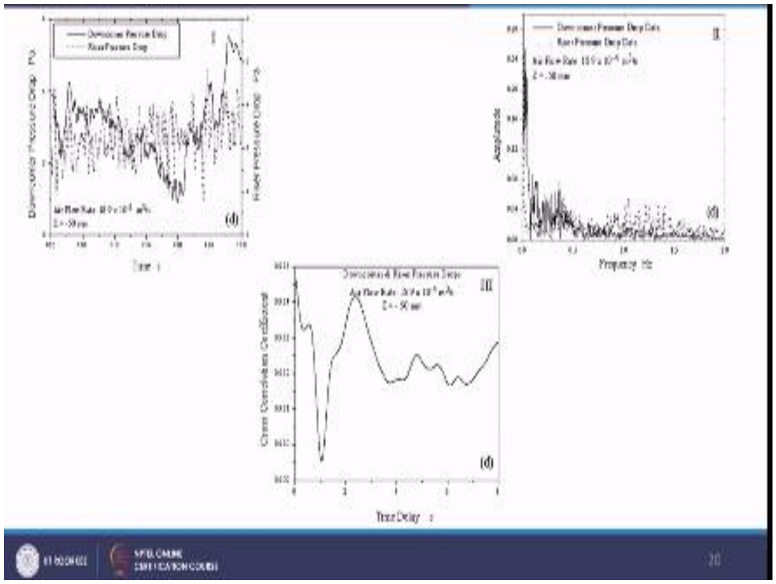

So it is double whatever, I have shown you in the previous one. Here you see the signal becomes very, very erratic because once you increase the air flow, it will be finding out that lots of bubble are actually interacting among themselves and forming a bigger bubble. So here you see the PSDF also looks like very much chaotic and if you try to correlate that means the cross correlation.

Then you will be finding out it is not showing oddly in nature whatever you have observed in the previous one okay. If you increase the velocity further you will be getting further erratic nature. Another important technique I will be showing you apart from this PSDF that is called actually scatter.

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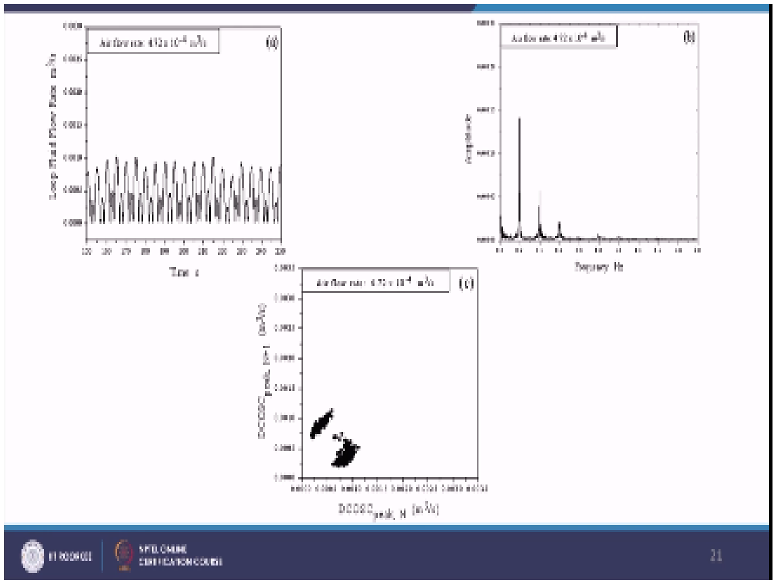

So what we are having we are having the signals like this. Let say a different time we are having signals like this. Now what we can do, we can let say the signal is in column. So I will be calling the signals as vn, vn+1, vn+2, vn+3 like this. So in are the different time levels. So what we can do, we can plot the signals like this in a voltage, voltage plane or signal, signal plane like this.

This is for the voltage at or the signal at n +1 at time s and this is ns time. To give little bit more idea it is like this that let say you are getting the signals likes v1, v2, v3, v4 like this. So first you will be plotting v1, v2 and the stance will be plotting v2, v3 and subsequently v3, v4. So abscissa and ordinate will be altering each other. So you see in this case at low flow rate, you are finding a two lobe this like this okay.

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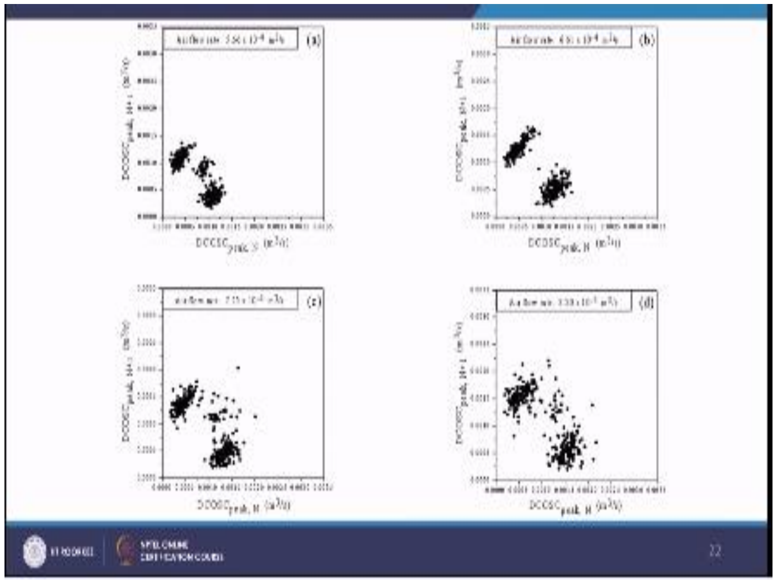

Once you increase the flow rate then you will be finding out here I have shown based on the flow rates you see once you increase the flow rate this 2 lobe thing forming into 3 lobe and subsequently it is actually increasing the scatter once the velocity is increasing okay. Continuing like this at a very higher velocity, you can find out it is becoming very erratic, showing the erratic nature of the 2 phase distribution okay.

Corresponding PSDF also I have probably density function. I have also shown you over here which is also very, very chaotic. So showing a chaotic nature inside the pipeline.

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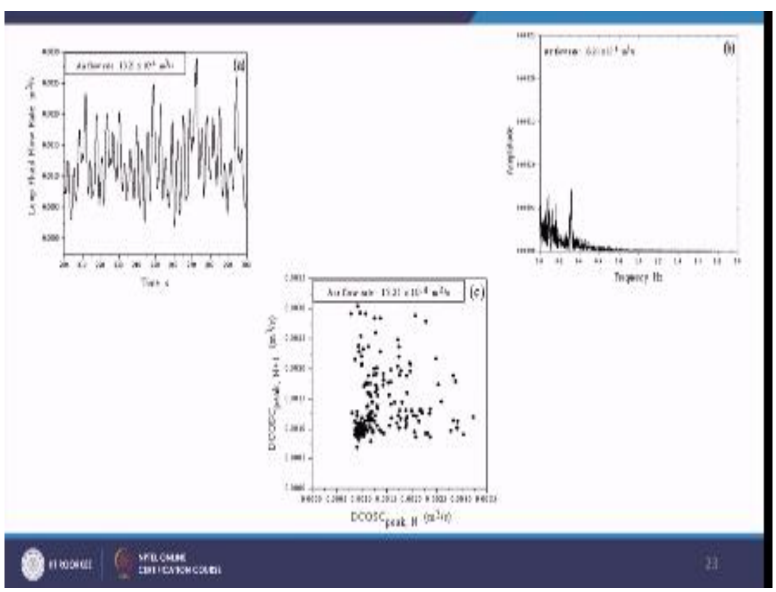

So by doing this kind of post processing of the signal as what you can do, you can find out what type of regime is occurring inside the pipeline. Okay, next I will be giving you further idea about the signal processing. So from 2d plot I will be showing you a 3d plot which is called a time delay plot.

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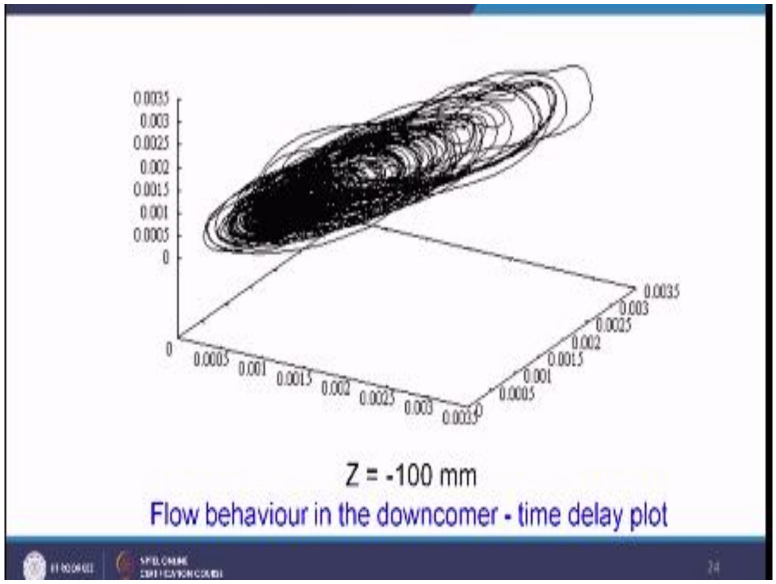

In case of 2d plot you are having vn+1 and vn. Here I will be showing you vn+1, vn, vn-1. So in x, y and z coordinator respectively, you can take all these points. if you are having a series of points in a column so you can always choose 3 consecutive points one by one and you can plot it in a 3d plane. So then in 3d plane looking like this okay.

It says this 3d plot is actually for z = -100 mm of the channel okay. Okay after that I will be showing you a technique of data fusion okay. In using our tomography probe so here in case of tomography probe we know that we are having optical sensors.

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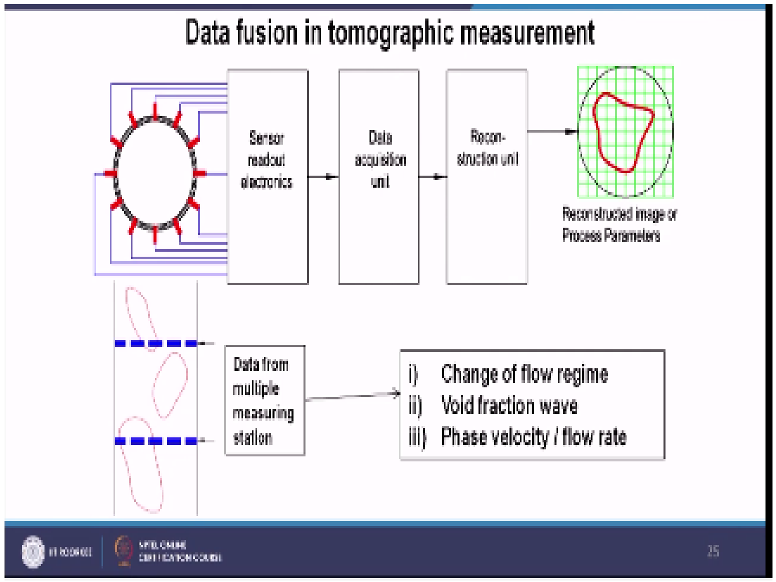

So we are having here optical sensors in the periphery of the pipeline. So lots of optical sensors we have given in the sector you see and all the signals are actually coming out over here in the readout. And then from the readout we are going to data acquisition system and finally reconstruction is being done for the interface.

Now I explain little bit about this type of reconstruction. So here I have shown you this technology reconstruction technology using wire mesh conductivity probe signals. So here in wire mesh sensor the pipeline is actually the constructed in the form of a wire mesh. So you see this is numerical mesh kind of structure okay so this is a numerical mesh structure will be getting the voltages.

To give you more detail, here I have shown you the schematic let us say this is the pipeline through reach the Taylor bubble is flowing. So here what we have done, we have given 2 sets of wires okay.

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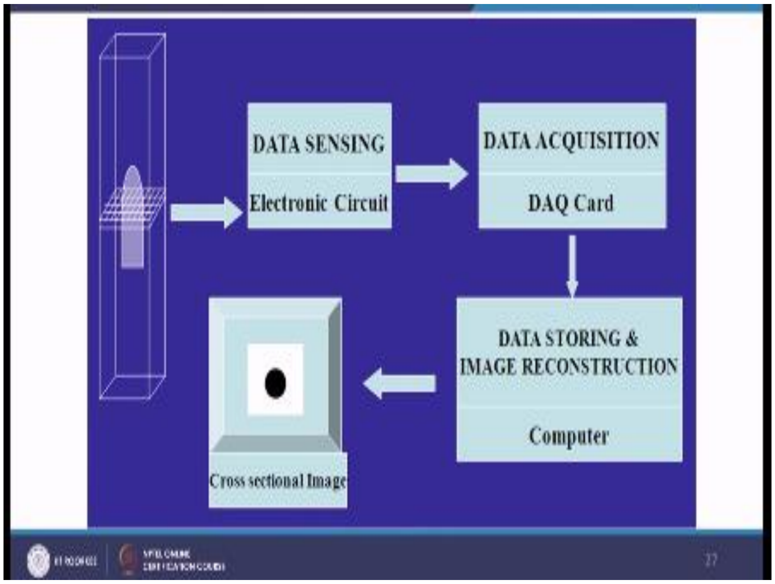

Parallel wire, first 1 is here which we can call as passive section will be at the bottom layer. There will be having wires parallel like this okay. At little bit top of that you will be have another layer where the wires will be in the cross direction okay. And those 2 wires, those to array of wires will be coming into picture in case of wire mesh sensor.

So lower 1, we can call as signal provider and upper 1 we can call as receiver. So using these signals what we can do eventually? Let us say this is a schematic of this wire machines. So here you can see both the layers are actually super posed and figure has been taken from top.

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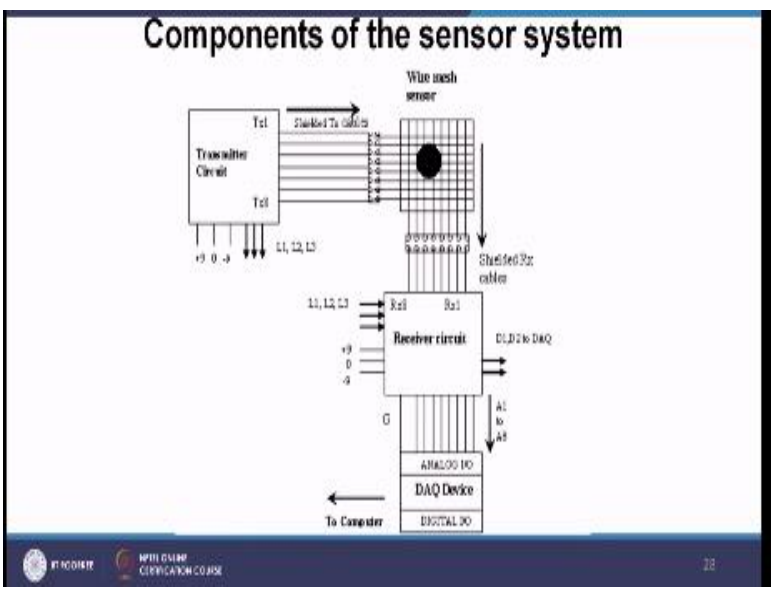

So you can find out that this vertical wires whatever we are having those are coming from the receiver circuitry.And whatever horizontal wires you are having those are coming from transmitter circuitry. So power is given to this 1 okay. Now what you can do at each cross point you can find out the voltage. As you are having a mesh kind of structure so from the mesh structuring at every point you can find out the voltage.

Now this voltage, you can record somewhere with respect to time that voltage will be moving up and you can find out that after sometime if you do the reconstruction from the voltages easily, the interface can not to do whatever has been passed through that mesh structure can be obtained okay.

A typical example I am showing you over here. I have shown you in the previous slide that it was taken for a Taylor bubble so you see this was a Taylor bubble moving in the upward direction. So after reconstruction we can get a similar type of Taylor bubble shape.

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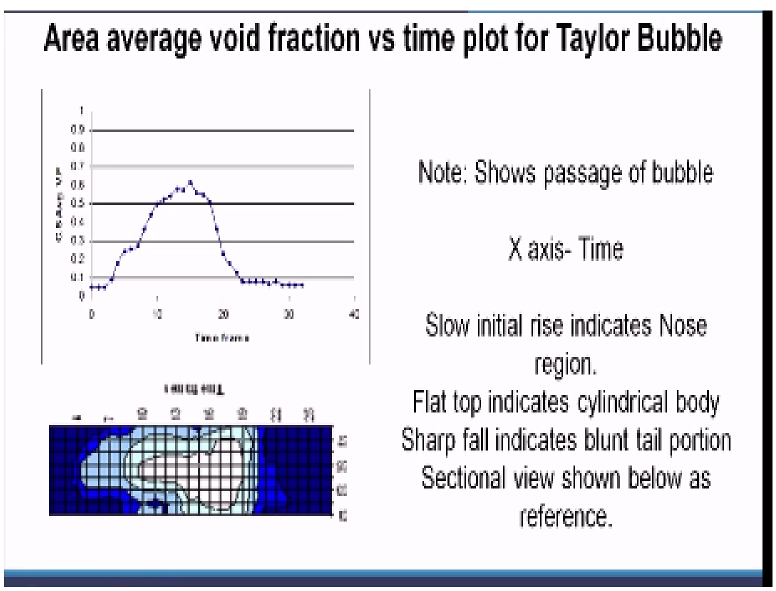

So if you go for more number of wires in the mesh you will be finding out better accurate interface over here right. So this is something related to your interface reconstruction.

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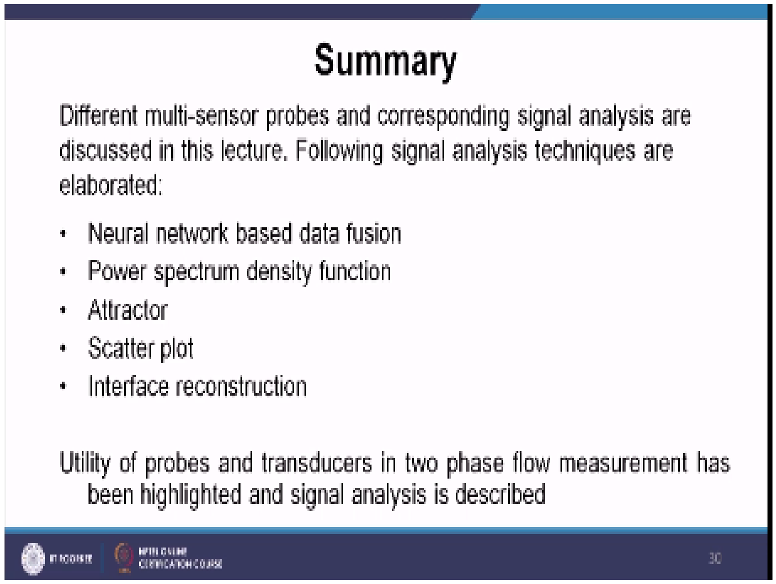

Now to summarize in this lecture what we have done, we have understood different sensor techniques over here okay. And we have understood how signal analysis can be done to obtain the features Two Phase Flow occurring inside the pipeline. So here we have discussed about neural network based data fusion in the first example I have shown you.

We have also talked about Power Spectrum Density Function PSDF in the second lecture we have talked about that. Attractor scatter plot and interface reconstruction also we have stressed. In the third part we have talked about attractor and scatter plot and in the last portion we have talked about interface reconstruction okay. So over all in this lecture, we have understood what are the essence of Two Phase Flow and measurements.

And how using signal analysis the quantitative and qualitative data can be obtained okay. At the end of this lecture let us test your understanding. So we are having 3 questions over here.

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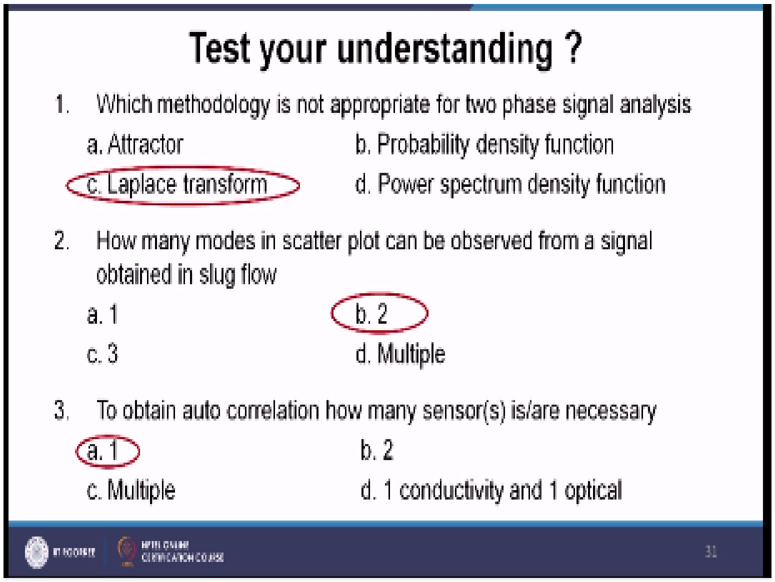

First 1, Which methodology is not appropriate for 2 phase signal analysis. We are having 4 answers. Attractor in part a, probability density function in part b, Laplace transform in part c and finally part d power spectrum density function. So as you have browsed both the lectures probably you have understood or learned so many times about attractor, probability density function and PSDF Power Spectrum Density Function. So only the unknown thing over here is Laplace transform so the answer is Laplace transform right.

Let us go to the next question, how many modes in scatter plot can be observed from a signal obtained in slug flow okay. So you are having slug flow so how many modes you can obtain from there modes means how many clusters in this scatter plot. So, definitely as you are having gas contact and liquid contact you will be finding out that you are having 2 modes. Here you are having answers 1, 2, 3 and multiple. So obviously, the answer is 2 mode right.

Third question to obtain auto correlation how many sensors is or are necessary. So if you have to have auto correlation so how many sensors are necessary. So we know that for auto correlation only single sensor data will be sufficient. So here answers are 1, 2, multiple and then 1 conductivity 1 optical. So obviously, answer will be single sensor is sufficient okay. So with knowledge we will be ending this lecture. Thank you very much.