Fluid Machines.
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Lecture-28.
Reciprocating Pump Part II.

Good morning and welcome you all to this session of the course on fluid machines. In the last class we derived the expression, an analytical expression from a very simple analysis of the moment of the piston, reciprocating motion of the piston, the expression of the acceleration head in suction or delivery pipes. And this can be written like this, the suction or the acceleration head, we discussed and which is like this. This head HA, the acceleration head which is written like this, length by G by the area ratio, area of the cylinder and the area of the pipeline, cross-sectional R Omega square cos Theta.

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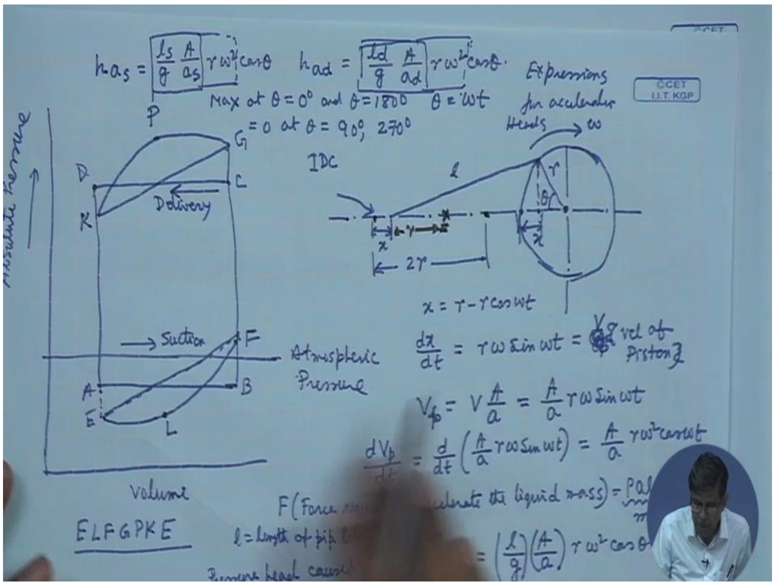

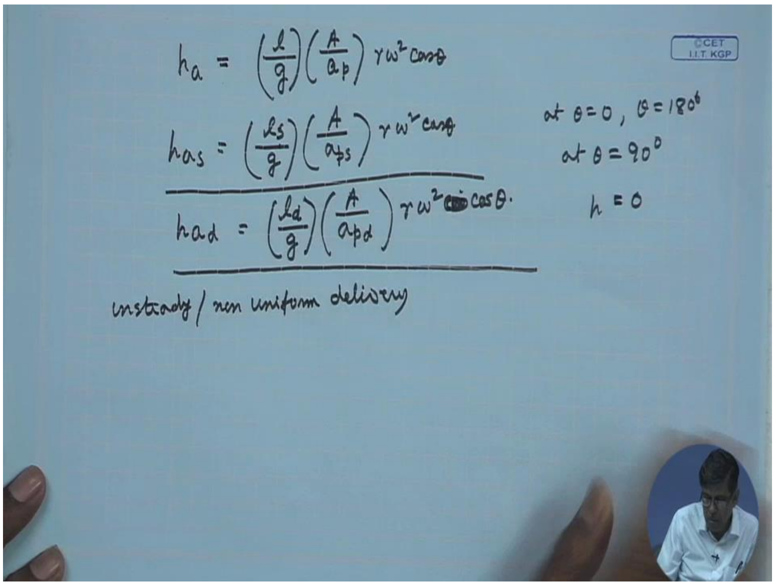

Now in the suction line, similarly head can be represented with the length of the suction pipe. So subscript will make the differentiation, that is the area of the cylinder, this is the cross-sectional area of the cos Theta. Okay. Then next is H, acceleration head in the delivery side will be, sorry, this is the length of the delivery pipe into this area ratio where this is the cross-sectional area of the delivery pipe R omega square cos Theta, sorry my handwriting is bad.

So this is for, so the expression is same, only the lengths are changed, suction, delivery and the cross-sectional area. Now from here it is clear that at Theta is equal to 0 and at Theta is equal to 180 degree, the acceleration head is maximum with this change in sign. That means the acceleration gets maximum at the 2 dead centres, inner and outer dead centre. At Theta is equal to 90 degrees, you see the acceleration is 0, H is 0. That means acceleration is 0, whereas velocity is maximum. The velocity is maximum at Theta is equal to 90 degree.

That means if movement is like this, here you can see that the movement is like this, that at the dead centres, at the dead centres we have maximum acceleration and at the middle of the stroke, that is R, this is R, middle of the stroke, we get the maximum velocity but the acceleration is 0. And this is in consideration of the simple harmonic motion of this piston for a high ratio of L by R. Now therefore we have an idea that how the acceleration head is generated and how it is acted upon in the cylinder to cause a change in the head in both suction and the delivery stroke.

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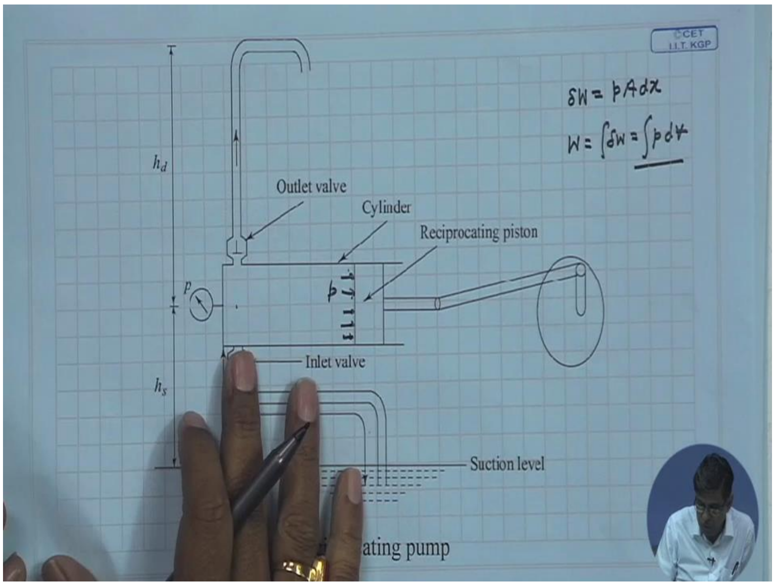

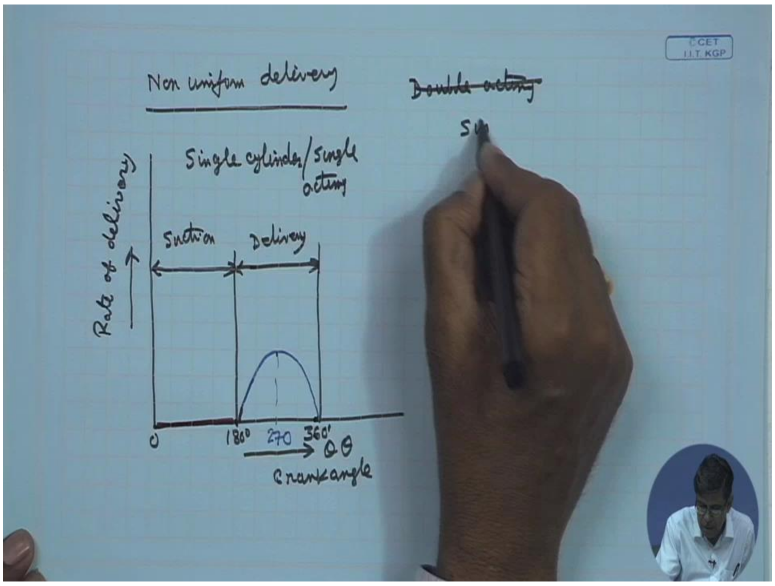

Now the most important part of the, this reciprocating pump is an unsteady and nonuniform delivery and nonuniform delivery, unsteady and nonuniform delivery, let us do it separately. That means it is not same with time. So unsteady and, rather I write nonuniform, that will be more suitable, nonuniform delivery. Why? Because if we express or show the rate of delivery, if we show the rate of delivery, the rate of delivery, if we show the rate of delivery with the crank angle Theta, that is crank angle, we see from 0 to, this is 0 to 180 degree is the suction, when it comes from the inner to the outer dead.

And from 180 degree to 360 degree, that means 0 to 180 suction, 180 to 360 is the, 0 to 180 and 180, 0 to 180 is the suction, 180 to 360 is the delivery. So you see during suction stroke, there is no discharge, that means this is suction, suction, there is no discharge. This is suction, so there is no discharge. 0, this is this, rather. Discharge the red one, now it is already black, there is no discharge. But during this delivery stroke, which is the delivery, this is the delivery one, it is very simple, delivery, in consideration of the simple harmonic motion we expect that this delivery with crank angle Theta, this is Theta will be a sinusoidal, a sine curve.

This I will do by different colour, so this will be like this. That means that 270 degree, this will be maximum. That means we get a typical nonuniform delivery for a single cylinder, single acting pump. That means there is a one cylinder and single acting means it has suction in one side, this is a typical diagram of a single cylinder single acting pump. That means this is a single cylinder, it has only one suction stroke and one delivery stroke. So during the suction stroke, this is closed, there is no delivery of the liquid.

But during the delivery stroke, the liquid is discharged. So therefore suction stroke 0 delivery dead and delivery stroke, there is a delivery dead but during the delivery stroke, it executives a simple harmonic motion. Initially there is an acceleration and there is deceleration resulting in a maximum velocity at the middle of the stroke. So this results a variation in the flow velocity in a similar way in line with the velocity of the piston. And similarly the pipe velocity, only varies in the magnitude by the ratio of the area.

So therefore the discharge also, which is proportional to the flow velocity, there is in the same fashion has a sine curve. So you see we get a nonuniform distribution. Now if you have a double acting, if you have a double acting, this is single cylinder single acting, single cylinder and single acting. Now a double acting but single cylinder, rather I write single cylinder, single cylinder but double acting. What is double acting? Double acting means it has the inlet and outlet valves similar in the both sides of the cylinder.

That means when cylinder executes a suction motion in one side, left, it executes a in the right part of the liquid, it discharges it. That means, when the piston aggregates a reciprocating motion in one side of the piston, there is a suction created, another side of the piston, there is a discharge created. So therefore this piston can, similarly happens that we can comes the other direction, the side which was at the discharge side will be will be suction and the suction side will be discharge.

That means piston can take liquid both sides and can discharge liquid from both sides. That means both the side there is a delivery line, both the sides are the suction line and the valves arrangements are like that. Sometimes ports are also given which are designed in such a way, which automatically close and open, along with the motion of the piston. So this way the arrangements are made on both sides, a piston is known as double acting piston. That means it has, one stroke, it has both suction and delivery.

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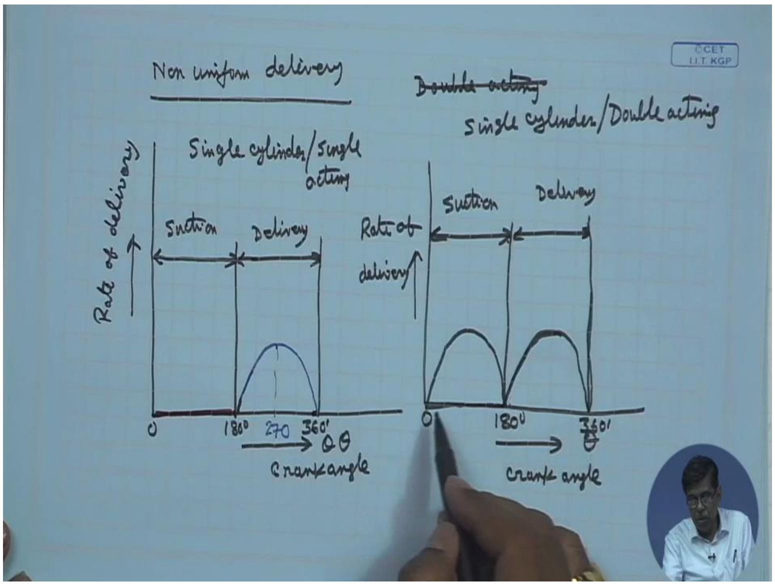

That means in a complete cycle it has throughout a delivery, it is not like a single acting during the suction stroke, half period of the water cycle is without delivery. Okay you understand. So it is very simple to make a diagram. So here what will happen, this is rate of delivery, rate of delivery versus the crank angle Theta, the crank angle. Now here what will happen. If we just divide this suction, sorry and the delivery like this, this is the suction. So suction stroke means suction on one. So therefore there is no meaning of suction and delivery.

So though I am writing it, this is meaningless, this is suction on one side, delivery on other side, just to make a comparison with that. That means if I divide it, the crank angle into like this, 0, 180 and 360, then we will be having a sine curve in both sectors, that means we have a flow, rate of flow velocity or rate of delivery as sin curve with 180 degree phase lag. That means 2 sine curves with 180 degrees phase lag. So there will be nonuniform distribution but continuous distribution of delivery.

Here delivery is not continuous and at the same time nonuniform. But here delivery is continuous, continuous we have a delivery, but the delivery is nonuniform. So therefore you see, make the cylinder, pump cylinder double acting, we have a continuous delivery but nonuniform. But this nonuniformity of the delivery will always be there because this is inherent nature of this type of pump because of the motion of the piston which executes acceleration, deceleration, which is involved in its motion with acceleration, deceleration.

But this can be minimised to a great extent if we use multiple pumps, more number of pumps. In multiple pumps what happens, more number of pumps are placed in parallel as you have come to know, the pumps in parallel and series are placed in parallel and with equally space in terms of the crank angle. That means total crank angle a 360 degree in its 1 revolution, so a number of cylinders are placed equally within the 360 degree. Let us give an example how does it make this thing.

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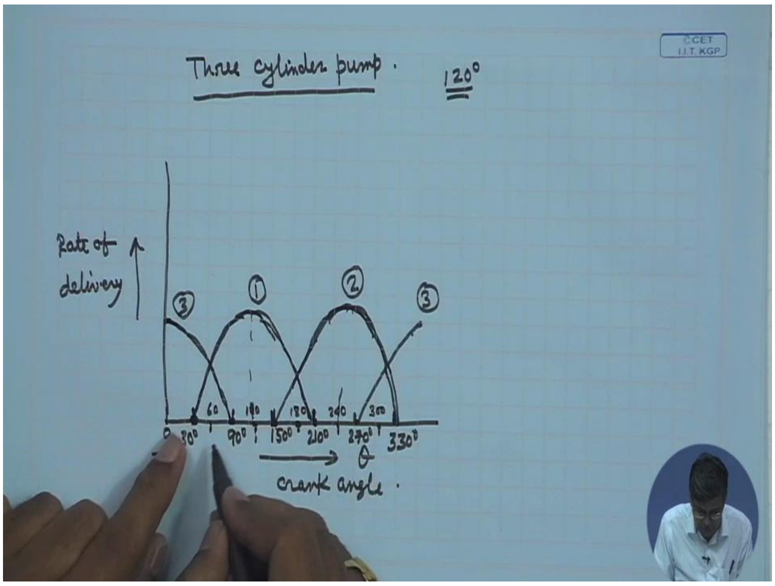

That let us consider a 3 cylinder pump. Let us consider a 3 cylinder pump, 3 cylinder pump. Which is, which are spaced 120 degree apart in the crank angle, of the crank angle. Crank has a rotation of 360 degree, so how does it make, let us see. Now this is the rate of delivery, this is the rate of delivery and this is the crank angle Theta, crank angle Theta. Now let us do this, this way, let us make, this is 30 degree, let, just let me do it, then I will tell you. This is 90 degree, this is 1, little, 150 degree, this is,2 times 60 degree apart I am doing, 270 degree and this is 330 degrees.

And therefore this is, I am not writing this, is difficult to write, 60 degree, this will be 120 degree, this will be 180 degree because this is 60, this will be 240 degree and this will be 300 degree. Okay, all right, this will be 60 rather here you write, this will be 120, this will be 180, this will be 240 and this will be 300, this is the graduation. Now this will be like this. One cylinder, let this 30 and 180, it is 180, so 30, it starts 30 and it goes 210, sorry, no 210, that means, let us consider this as the discharge profile as we have already studied for one cylinder which starts here at 30 degree crank angle as the stroke, 1st stroke that is suction stroke and ends at 210 degree.

So during the, sorry, suction, not delivery stroke, whose delivery stroke starts at 30 degree sorry and ends at 210 degree and gives the discharge like that. So another cylinder which is 120 degree away may start at 150 degree because this cylinder pump arrangement at 150 degree and will end at 150 and 180 and 330 degree. That means this will be, let us consider they are of the, so say profile is same, they are of the same, sorry, 330. They are of the same type, that gives these 2.

So this is in phase difference of 120 degree. And this maximum comes at 150+90, 240 and here also this comes at 30+ 90, that means this is 120. That means this is 120, that means the maximum is 120. That means this is, the discharge profile of the one cylinder whose discharge stroke or delivery stroke is 30 to 210 and 120 degree phase lag, 150 to 330. Similarly another cylinder will start, 150+ 2 is 270. So it will go like this 270 and it will here, this will be 360 or 0.

0 means 360, this will start at 270 and if you, at, this is 360, so it will be ending at 90. So therefore which starts at 270 will be ending at 90 for 180 degree because 360, 90 and again 90. And its maximum is there at 360 because 270+90 is 360 and 270+180 will come to 90 degree. 360+90, so this is another cylinder. So I think you have understood. If this is cylinder number 1, this is cylinder number 2, this is cylinder number 3. Or you can think other way. This is slender number-one, so cylinder number 3, so cylinder number-one, cylinder number 2 and cylinder number 3. This part and this part together gives the same profile for cylinder number 3.

That means they are 120 degree in phase lag and all of them are giving the similar nonuniform but a sine curve type of thing if we consider the simple harmonic motion of the piston, the rate of delivery with 120 degree apart. So therefore you see there is still uniformity but the fluctuation is little bit reduced in this way that if you see this, that from 30 degree, here you see, here 30 degree, it starts from 30 degree to 90 degree, there is an overlap, 30 degree to 90 degree, there is an overlap. So this part, the discharge will be added, discharge of the machine 3 + discharge of the machine 1 and if you add these, this will be like this.

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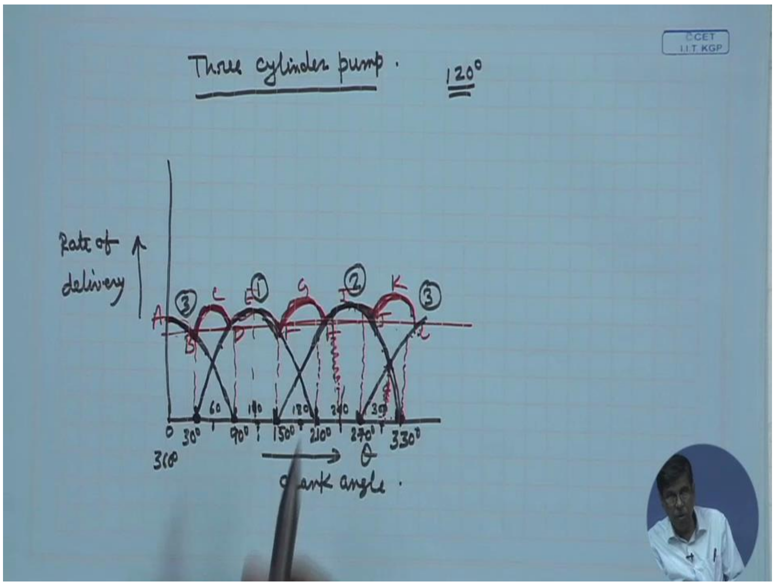

Sorry, my drawing is like not very good. Similarly from 150 degree to 240 degree, this 90 degree difference, the scaling is also not that good. There is an overlap, sorry, sorry, sorry, this is 210 degree, I am sorry, not here, 210 degree, then it is okay. Now this 60 degree, here also 30, 90, 60. So 150, after 150 up to 210, there is an overlap between the discharge of 1 and discharge of 2. So therefore in between this crank angle, the net discharge will be the sum of the discharge from piston cylinder 1 and cylinder 2. And if you make this, this will be like this.

Similarly here also, from 300 here, not 300, sorry this one, 300, yes, this is 300. 300, okay. Where it cuts here, that is 300 and where this is 0, that is 300 to 270 to 330, sorry, not 300, 270, from here, not 300, 330, that means this part. 270 and 330, there is an overlap. This is going up, so there is an overlap, so this will be like this, the net discharge, the sum of 2 and 3. I am sorry, from 270, the overlap starts because here this part is there, this part, volume part, rising part and they intersect here. After that, this comes, so up to 330, this is there. So from 30 to 90, there is an overlap between 3 and 1.

30, where from the 1 starts and 90 where the 3 falls, so there is an overlap. So the net discharge will be some of these 2. Similarly from 150 where the 2 starts, the discharging, the pump 2 starts discharging up to 210 where the pump 1 stops discharging is the overlapping and then it discharge will be like this. Similarly here, 270 where the pump 3 and the 330 when the pump 2 ends in discharging in the overlap. So therefore if you now, draw this curve, this will be like this, the final curve is like this, final curve is like this.

The final curve will be A, B, C, D, E, like that, F, if I write, G, H, I, J, K, L onwards. That means this is, so in this case still it is fluctuating, fluctuation cannot be totally minimised but this gives more or less a uniform flow. We can make a mean line about which the fluctuation is there. And if you have more number of pumps instead of 3 cylinder pumps, equally between the crank and within the crank angle of 360 degree on revolution, we get a more even or uniform distribution. Still there will be a fluctuation like this. So this way using number of cylinders we can reduce the fluctuation and can get uniform discharge rate from a reciprocating pumps.

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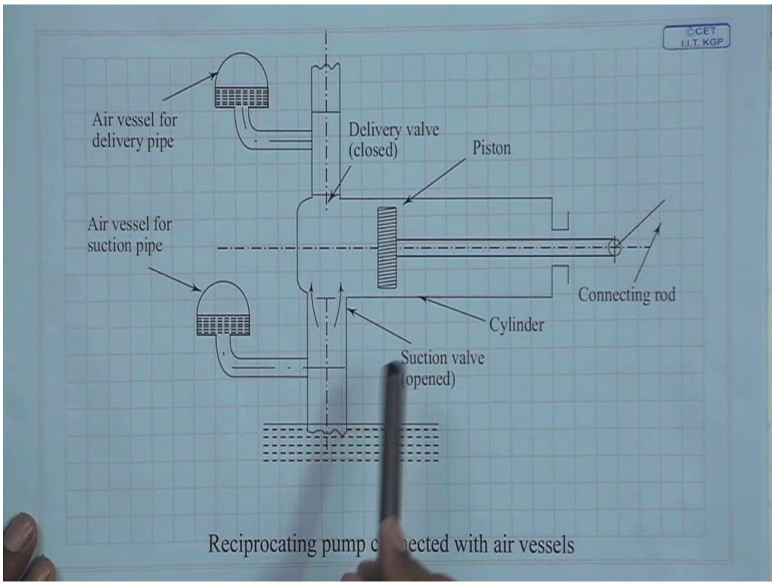

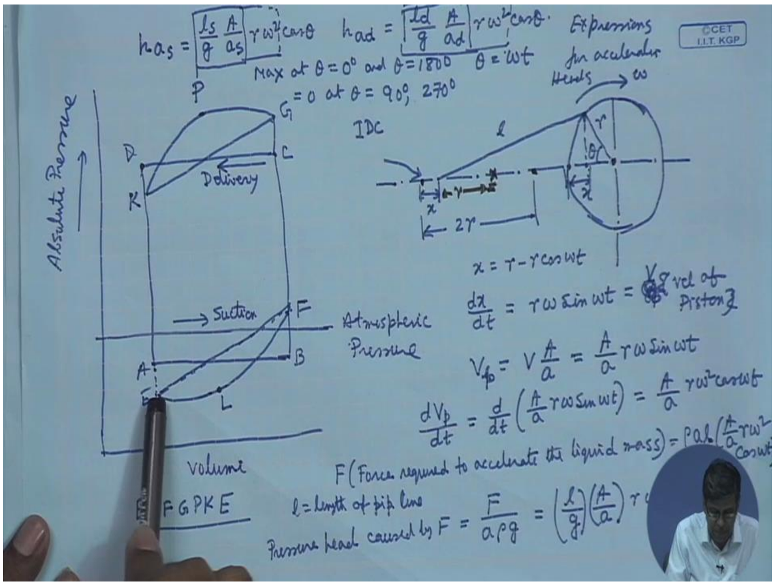

Now next what I will tell is the concept of air vessel. Now to make the discharge more uniform or almost exactly uniform I may say and to save the pipeline in the suction side that I will explain, air vessels, there systems known as air vessels are incorporated in a reciprocating pump. How does it look, you see, this is a reciprocating pump, air vessels are the vessels closed in one, contains water and the air above it which is at a higher pressure. And these air vessels are connected in suction side and delivery side as close as possible to the pump cylinder.

That means this should be as close as possible to the pump cylinder in the delivery side, this is in the suction side, this is air vessel for the suction pipe, this is air vessel for the delivery pipe. Now these air vessels act like a flywheel, what is the function of a flywheel? Flywheel stores energy, extra energy when it is given to you and it has to be removed from the system and it supplies extra energy when it is required and it stores energy and gives energy, it can do so by its huge inertia.

So here also this stores extra energy and gives extra energy by this compressed air. Now when the air is compressed by the movement or the inflow of water here, it takes energy. That means when there is an excess water in the pipe and it has to be reduced, water comes here and the air gets compressed, similar is the function for delivery pipeline. And what will be required in the pipeline, water will be given by this, by the expansion of the high-pressure air.

So therefore this air when it expands releases water or in terms of energy, energy and when it is required when it is compressed, then it absorbs energy. So therefore compressor and expansion of the air in the air vessel releases water or takes water from the line. How does it work you see, when it is attached to the suction line, then what happens that in the acceleration head, more water is required in this suction line. So okay, so this water will come here and this will be given by here so that the waste part which is the major part of the suction pipe, since it is placed close is slowing mostly with the same amount, same flow of water.

The flow of water is kept uniform, it is not changed but the acceleration, at the beginning due to acceleration head, more flow is coming from this. And similarly in the deceleration part of it, the water goes to that. So therefore the large portion of the suction pipe which is not clear from this figure is associated with the uniform flow. And therefore the chance of cavitation is reduced, only the fluctuation in pressure and the flow velocity of the discharge head which is inherent to the machine takes part only in the short column, or short length of the suction pipe between the air vessel and the pump cylinder.

Similar is the case for discharge. When the initial acceleration is high and discharge rate has to be more, so this releases water and goes like this. And a similar thing happens at the end of the discharge period. So therefore the rest part of the delivery line, just like the similar to suction line gets uniform discharge because of this air vessel, it gives additional air, water required, the initial part of the delivery stroke because of the acceleration head and similarly takes water to reduce it.

So therefore this part gives the uniform flow discharge rate because of this air vessel. Whereas this fluctuation takes place only here. You understand, so maintain a uniform discharge rate, the additional thing is taken up by this. That means when the initial acceleration is there, more discharge takes up by this, this part remains uniform. When the discharge is less, it gives less discharge at the rest part of the delivery stroke, this is being released.

So therefore you see here also the rate of discharge remains constant here. So additional discharge goes here, initial part and when the discharge rate is less at the end of the delivery stroke, then the water comes through this. So therefore this part of the pipe, the discharge fluctuating more at initial part in consideration of acceleration and less at the later part of the delivery stroke in consideration of its deceleration. But both the parts, this acts to absorb and release water, 1st it takes water in the initial part, the extra water so that this discharge rate is not hampered at and at the end it gives water, deficit water to for make up, so that this discharge it is not hampered.

So we get a constant discharge and constant pressure in the, this part of the delivery line. So this is precisely the function of the air vessel, to make the constant discharge at a constant pressure in the discharge line to make the suction line, for a greater part of the suction line to have a constant discharge without fluctuation of pressure. And this is the function of the vessels on 2 sides.

So from there we can summarise that incorporation of the air vessels reduces the possible, the suction side reduces the possibility of cavitation and we can use a higher length, more length of the suction in the suction side, pipe length and we can increase the pump speed because the pump speed is related to the minimum pressure in the suction pipe. That is the pressure E here, the pressure E the minimum pressure in the cycle, so minimum pressure can be increased. That means we can reduce, we can go to a lower minimum pressure so that you can avoid cavitation and length also you can increase.

And this incorporation of air vessels give the advantage that extra power required in providing the extra discharging time in case of additional acceleration head in the initial part of the delivery stroke through a long delivery pipe is saved. So it is the saving of power and another thing is the constant rate of discharge which is more important and which is not usually obtained from any reciprocating pump without the air vessels. Even the number of pumps, there will be a fluctuation but it will be relatively more uniform.

So this is the function of the air vessel and this ends today the lecture on reciprocating pump, hydraulic pump and today we close our lectures on hydraulic machines, that the machines using water or any other liquid. And next class we will start discussions on machines using air, air machines. Okay, thank you.