Corrosion Failures and Analysis
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Lecture - 36
Cavitation corrosion and its case studies

So, let us start lecture 36, and the course is Corrosion Failures and Analysis. We have been talking about Cavitation damage. We just started and in fact, we give an example that if you have a container and if we have a piston, if we increase the pressure and if we start with the water vapor it will start forming liquid. And if we decrease the pressure; if we decrease the pressure over liquid by pulling the piston out then of course, the liquid will start evaporating.

Now that happens at a constant temperature. And that can be obtained by putting entire thing in a constant temperature bath and then you can do that isothermal operation ok. So, this is isothermal operation by the piston and that piston increasing pressure actually takes the vapor from vapor zone to the liquid zone over that equilibrium point between liquid and vapor.

And that equilibrium point is actually following a curved data between pressure curve line which is the; which is the line drawn between pressure and temperature.

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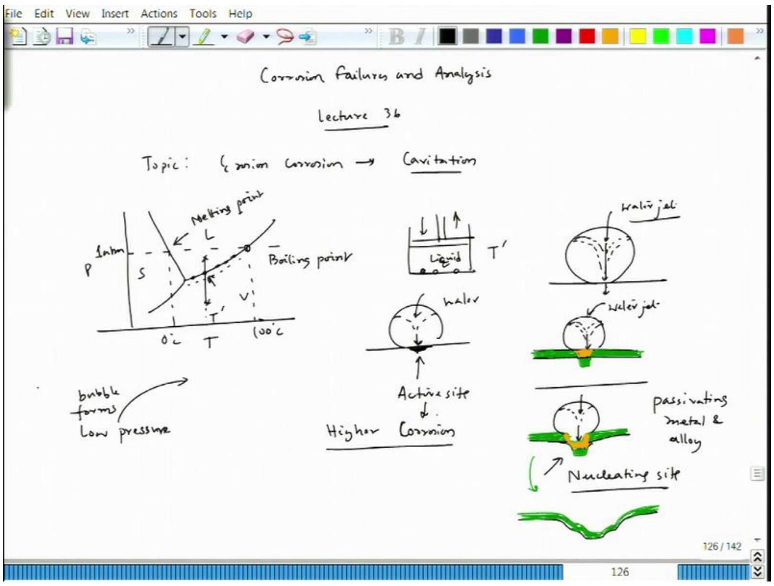

So, let us talk about cavitation corrosion. So, the course is Corrosion Failures Analysis and lecture 36. So, we talk about erosion corrosion and in fact, here it will be a special category of erosion corrosion that is cavitation damage; cavitation. Now, if we recall our discussion this is the water phase diagram. So, water phase diagram happens like this. So, this is solid, this is liquid, this is vapor ok.

So, now let us say if it is 1 atmosphere. So, then this temperature is 0 degree Celsius, this temperature is 100 degree Celsius. Now, at other temperature rather than 100 degree Celsius also we can have a boiling ok. So, this point is the boiling point, this is melting point, fine. So in fact, that melting point can also be consider freezing point. So now, boiling point now over this entire line; over this entire line every point is a boiling point ok.

So that means, at a particular this point let us say considered if we draw a parallel line to the with respect to pressure line ok; so then at this pressure for this particular temperature let us say T prime it will be liquid at this pressure at the same temperature T prime it will be vapor. So that means, here the transition takes place from vapor to liquid or liquid to vapor. So, we are bothered about this particular transition ok.

So, we are actually considering this transition and that leads to cavitation. And we have given an example that this particular example we have talked about, it is a basically piston and it is kept at a in a constant temperature, but T prime and if pressure reduces you know over a liquid; over a liquid this vapor forms and then again pressure increases, this vapor will collapse.

Now this, so, this vapor actually forms in the form of bubbles. And in fact, if you increase the pressure bubble will collapse. The bubble collapse takes place like this. So, if this bubble is forming over the surface then this particular surface it will prevent that bubble to spread ok. So now, because of the increase in pressure it will break like this; break like this.

Now, when this breaking happens water is following that particular break points those hinge points and then finally, it is forming a water jet ok. So, this water jet when the bubble entirely collapse this water jet falls on top of the metal and then it actually tries to give a huge pressure which is of the order of around 500 megapascal which can deform the surface.

And or we talked about deformation of the surface in the previous lecture, but if let us say the surface is covered with a passivating layer or oxide layer that because of that particular high pressure that at that point of heating of that jet over that particular metal surface the passive layer can break open ok. So, then it will expose the fresh material and if it is not having any passive layer then the base metal can deform.

So, deformation can lead to extra corrosion ok, and then again on one bubble form because of this decrease in pressure and the next process increase in pressure bubble collapse like that process go on. Now, we talked about deformation part. Now, if we let us say this is the passive layer that has formed, now the bubble has formed. Now, that bubble is collapsing. Water jet is actually following that collapse point.

Now, it hits here and because of hitting let us say a small portion of that particular section is exposed fine. So that means, this is the part which is exposed to the electrolyte. So now, if it is a passivating one in that particular electrolyte the next passivation layer would form, this passive layer would form, fine.

So, now little bit of passive layer little bit of material would be lost in the form of that lost rust and the next rust will form or the next passive layer would form. The next cycle again another. So, now, you have a situation like this.

So, this is the thing and now the next bubble the possibility of formation of bubble due to reduce reduction in pressure would be maximum would be very not maximum; I would not we should not say that particular part that maximum there will be possibility would be very high at this point ok. Why? Because this provides nucleating site is a scratch surface.

So, that is what for example. So, this scratch surface if it forms again, again that bubble will collapse, water jet will hit this surface. The next process would be this particular segment would further damage and that damage will be also extending sideways little bit.

So, this surface would be like this and the last layer would be. Again, so this particular section goes off. So, this particular section goes off, the rust will go off and then here also a part will again repassivate, this will again repassivate ok. So, that is what it is indicated here. Again repassivation, like that the material losses taking place. This is in case of passivating metal passivating metal and alloy.

But if it is not passivating of course, the passive layer is not breaking, but it will be; it will be deforming because of this effect this water jet that is impinging on this particular surface, this surface would be deformed, this is the deform part. So, now, this is active site and that would lead to a corrosion ok higher corrosion higher degree of corrosion; higher corrosion.

So, then this part will corrode to some extent and the next bubble forms and then again that bubble collapse happens. So, like that way those cycle will move on. The cycle is like this: low pressure bubble form. Why bubble forms? Ok. So, let me draw it here. What is the cycle?

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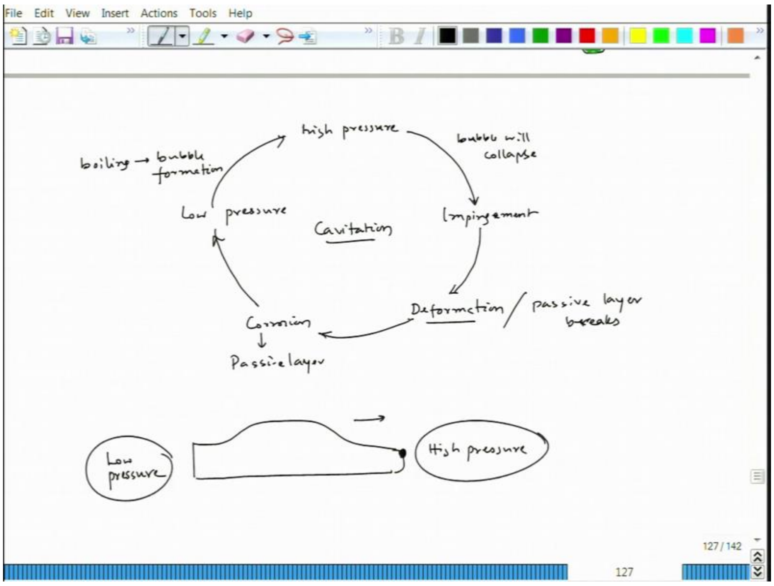

First is low pressure then boiling happens. Boiling leading to bubble formation. Now, if it goes to high pressure, so, then there the operation would be bubble will collapse because vapor will convert to water. So, this bubble collapse will lead to impingement and that impingement will lead to deformation.

So, the deformation would lead to corrosion and then again next bubble forms and like that way the entire cycle when it happens, the damage happens and through the deformation mode that time we call it cavitation. So, this is in case of a non-passivating metal and if it is a passivating metal then here when the impingement happens the deformation instead of deformation here passive layer breaks ok.

Then passive layer, when passive layer breaks and that time corrosion happens that corrosion leads to formation of passive layer. And then passive layer again low pressure happens, boiling, bubble formation like that with this circle cycle will move. So, this is basically a typical a cycle of cavitation.

Now, interesting part is we have been talking about low pressure and high pressure, fine. Now, question is we are doing an experiment in the lab where we are decreasing the pressure by pulling the piston out over a liquid or increasing the pressure by pushing the piston in into the liquid. So, this laboratory experiment is fine, but now thing is whether this can be achieved in a component or a moving component, fine.

Now, in case of static component until and unless the atmospheric pressure drops we do not experience such experiment such kind of thing ok, but if it is a moving object then of course, pressure drops ok. For example, I am just giving you one typical example. Let us say this hand if you just wave through for example, I am waving through this hand you will see that this back of the hand you will always experience little bit little bit of cool air coolness here ok. You could feel that the back of the hand is actually getting little bit of air flow from outside ok.

So, this movement ok; so, this movement what if happens there? When we move like this, quickly if you move, you will feel more cooler air coming on the back side ok. So, this happens because we are actually pushing the air like this waving hand and because of the push; the front side of that particular push will have high pressure, the back side is actually having low pressure.

And because it is creating low pressure the back side when you move like this the air from surrounding atmosphere is actually trying to fill that particular low pressure zone and that is what you are feeling a little bit of coolness there ok, fine. So, this is this happens whenever a something some object moves very fast ok. The back end of that object will always create a kind of low pressure zone. For example, a car ok or a bus.

If it moves at a high rate ok, so, that time the low pressure would be created and that actually allow allows those air molecules to come from outside to the back end. For example, if it is a car; if it is a car and this is the; this is the front end this is the front end ok. So now, if it is moving at a high speed, there it will be low pressure and here it will be high pressure and this dynamics is very complicated, but at least this is very very true fine.

Now that means, any object if of this particular if it is going through the air; now if something moves in a fluid or liquid at a high speed and if it is dragging the liquid you would also see that the back end is actually having low pressure. For example, you just do for example, a small experiment.

Take a bucket full of bucket a long bucket ok and then try to pull your hand through that particular water you will see that the back end will have a will create a kind of vortex and there water will start coming from surrounding. So, this is also a kind of low pressure zone created at the back end fine. So, this low pressure creation is possible whenever there is a moving object in a fluid or in a liquid. So, there the pressure can drop and that boiling can happen ok.

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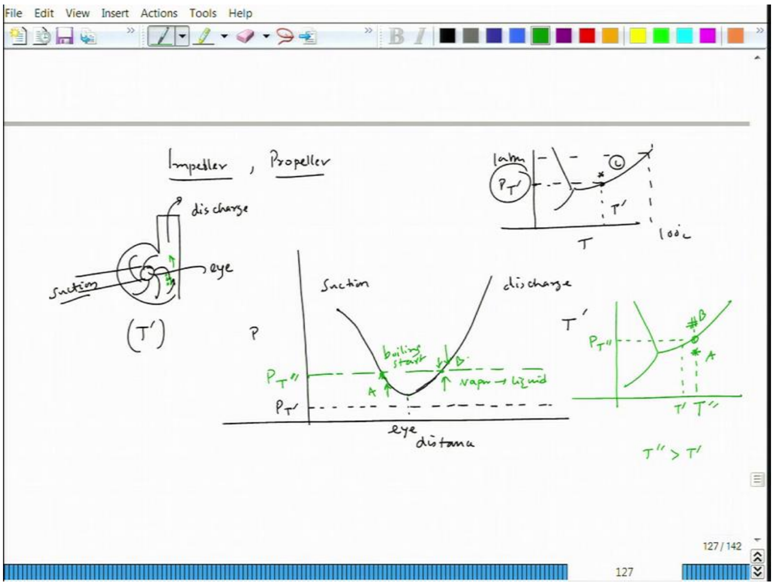

So, there we have cavitation and where we can have those kind of situation? Like impeller, propeller. So, those kind of situations we always experience low pressure at the back of the blade of the impeller, back of the blade of the propeller ok. So, there water can boil.

Even the temperature is less than 100 degree Celsius water can boil because it is basically the phase diagram that is playing a role. If it is this is the pressure temperature phase diagram of water and now this is my 1 atmosphere pressure the boiling point is 100 degree. And if the pressure drops to let us say very low.

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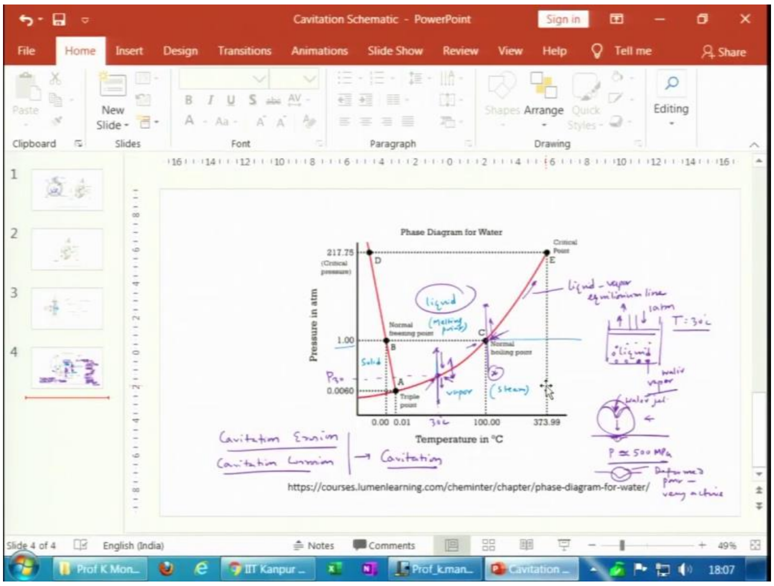

If I try to look at this particular diagram let us say pressure goes to as low as around 0.5 or 0.4 atmosphere, so, then it can boil at a much lower temperature, fine. So, that thing actually exactly takes place. Even at a room temperature water can boil. Now, that boiling would lead to an in a liquid water if boiling happens that would lead to a small bubble ok.

So, that bubble does not contain air it contains steam. And that bubble can burst if in that system somehow it goes into a high pressure zone ok; so, then that bubble can collapse. For example, let us look at the centrifugal pump and impeller blade situation.

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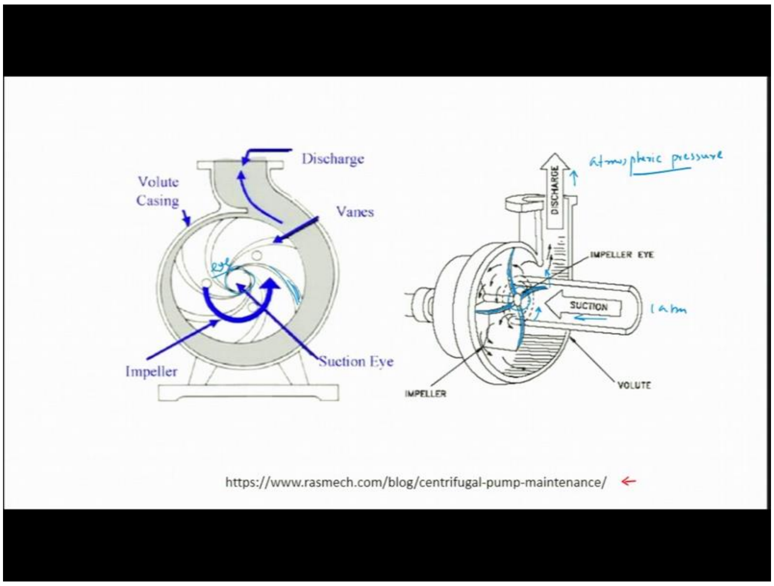

Let us go to that. Here also since this drawing is complicated for teaching purpose I have taken it from this particular site. You can go and look at this site ok. This is for education purpose. Now, what happens? This is a simple pump, a centrifugal pump ok and in that centrifugal pump this is basically the inside that casing we have those impeller blades. So, these are the blades ok. So, this is a blade. So, this is impeller blades that blue color. So, these are the blades fine.

So, now these are the blades here, these are the blades. Now, it has mainly three component, there are different components. I am not bothered about those components I am looking at those components which actually develops those bubbles. Now, this is eye of impeller. So, this particular part where and this is the part ok. So, this is the eye impeller eye.

Now, this is the suction zone through which the water is sucked in. Now, how come water can be sucked in? Ok. The only possibility is if there is a low pressure the low pressure will take the water inside that through that eye into the impeller; on to the impeller rather ok inside the casing. Now, this impeller is moving at a high speed. The impeller movement is this way ok.

Because of this impeller movement the suction is created and the water is taken into the chamber. And that chamber this impeller blade when it goes to this ok around this section this water is thrown to the outside through this outlet ok. So, this outlet is called discharge ok. So now, question is until and unless the pressure is dropped in the eye region suction cannot happen and then it has to thrown into the atmosphere.

So that means, this is you can say atmospheric pressure. In fact, this pressure goes beyond atmospheric pressure ok. So, then when it goes outside then the pressure becomes atmospheric pressure. So, now in the suction zone pressure start reducing. Away from the suction zone it will be 1 atmosphere, the water is at normal pressure.

Now, as you are suctioning then the pressure is dropping. In the eye region the pressure would be minimum and then as the water goes to the discharge region the pressure would again start increasing. Now, this is the decrease in pressure and then increase in pressure that leads to a situation of bubble formation or boiling situation as well as conversion of steam into liquid again.

So, let us look at how it happens. Now, here in case of impeller; so that means, if we see clearly that we have our design like this, fine. This is a simple design. So now, the simpler plates are designed like this ok. So, now, it is moving this way. So, the water is taken out, this is discharge, this is eye and let us say this is a suction zone. Now, if we try to look at the pressure variation from suction due to discharge of that water we can have a plot like this.

So, let us say this point is suction. So, I am talking about this zone, this is a suction zone ok. So now, and this is the eye zone, this is the eye, this is the discharge. So, that is what we are looking at now suction zone it is coming just start of the suction zone you can see its 1 atmosphere.

Now, the pressure will drop. Pressure drop is taking place. Let us say it is not linear. So, like this and then it goes to eye ok. Now, after it crosses I the water pressure would again increase. So, this is the kind of variation of pressure of that water from suction to the discharge zone, fine.

Now, if we try to look at the temperature at which that pump is operating. Now that would also have let us say this is the temperature T prime. So, that time this is the pressure T prime for the boiling to happen. If that particular point is lying here; lying here, this is let us say P T prime. Now, all the pressure from suction to eye to discharge is basically beyond the pressure required for boiling at T prime temperature.

And this pump is P impeller is or pump is of P T prime ok or; sorry at T prime this is the temperature of water ok. So that means, this is that particular pressure point where boiling starts. Now, actual pressure in the lowest pressure region which is the eye pressure is at this point fine and rest of the pressure starting from suction to the discharge will be all at a higher level. So, everything will be liquid, no problem ok; no vapor formation or no steam boiling. So, there will be no question of forming bubbles.

Now, if the pressure this particular pressure line is here. So, let us say this is instead of P T prime instead of here if it falls here ok then what happens? You see at this point when the water moves from suction to eye the pressure drops below the boiling point at T prime ok. So, now, instead of T prime let me put T double prime. So, let me draw a separate graph for that.

So, now this was the T prime. So, now, this T prime let us say a little a higher temperature. The pump is operating at a little higher temperature fine. So, this is P T double prime. So, this is P double prime, it had little higher and this was at T prime. The pump is taken the pump is operating at a with the water which is having T double prime temperature and T double prime is greater than T prime.

So that means, that pressure line the pressure for boiling would be lying here and if we draw a parallel line with the distance that will give you the pressure line. Wherever that pressure line is crossed by the pressure of water there will be boiling happening. So, now here boiling start and here vapor to liquid conversion will take place ok.

So now, when bubble forms, no problem. Bubble will stay, but when this bubble comes here when the water goes away from the eye zone towards discharge zone at this point the vapor converts to liquid because the pressure line is crossing this point. So, it is initially it was here at this A location and let us say this is B location, this is A location and now when it reaches to this, so, just a minute. So, let us say little down this. So, let us say this is the A point. So, the A point pressure was here this is A.

Now, B point let us put this B point little above. So, here let us say. So, the B point is here ok. So, this is the B point, fine. Now, see the difference. When it is A point, it is all vapor; that means, those and the liquid cannot convert vapor all on a sudden. So, it will convert gradually ok.

So, now, that vapor is forming in the form of bubble and then when it crosses this point when the water moves from eye to the discharge the vapor is or the those vapor is converting to liquid. So that means, the bubble has to collapse ok and that bubble collapse leads to a water jet falling impinging on top of metal surface, fine.

So, now when it reaches to the discharge location those bubble will collapse and those bubbles are forming on top of impeller blade and then bubbles are collapsing on top of impeller blade. And now the bubble formation now will be more, if the impeller is moving this way the bubble formation would be more on the back of the impeller ok. And this back of the impeller will have a serious cavitation damage.

And the damage mechanism is same. Impingement by a water jet due to bubble collapse and then either passive layer formation or the breaking of passive layer and then repassivation or it can deform the surface and then corrosion would happen. So, like that way the cycle what I have shown, so, that cycle will operate.

So, this is the cycle that would operate there, but actually this is the situation what happens in case of pump. The pressure line which corresponds to the boiling at that temperature of water that pressure line is crossed from suction to the eye and that crossing lead to vapor formation. And when the water is moved away from eye to the discharge at one location that pressure line P double prime will be crossed due to high pressure. And those bubbles will collapse due because it has to collapse because collapse because the vapor has to convert to liquid.

So, that thing happens continuously because this particular tank; this particular pump will keep on operating and P keep on sucking water through the eye and leaving it to the discharge. So, that way this cavitation damage happens in a moving object wherever a fluid is taken with the particular moving object. So, this is the situation in case of impeller or normal household centrifugal pump ok.

So, this is one such instance where cavitation damage happens over the impeller. In fact, this impeller blades can be broken into pieces, small small pieces will happen. And another interesting part which I missed that when the bubble collapse it actually leads to a shock wave, ok. So, that shock wave would also lead to a damage to the material, and this bubble collapse can also lead to a sound ok.

Now, more the bubble higher would be the sound. And interestingly as the impeller blade is getting corroded due to cavitation damage or getting damaged due to cavitation erosion whatever you say because of that the more number of bubble will start forming because it is actually making impression on that impeller blade. Initially, it started with a very fresh shiny blade, but gradually it will become bit become a dented blades and there bubble will form and it will create lot of sound.

Interestingly the pump starts creating sound and that time we have to be careful that there something wrong is taking place in that particular pump. And mostly, in most of the cases it is basically the cavitation damage related phenomena as the time passes with the particular operation of the; operation of that particular pump. So, this is in short that what is cavitation damage and how it happens in case of moving objects in fluid or liquid, propeller also the same thing happens.

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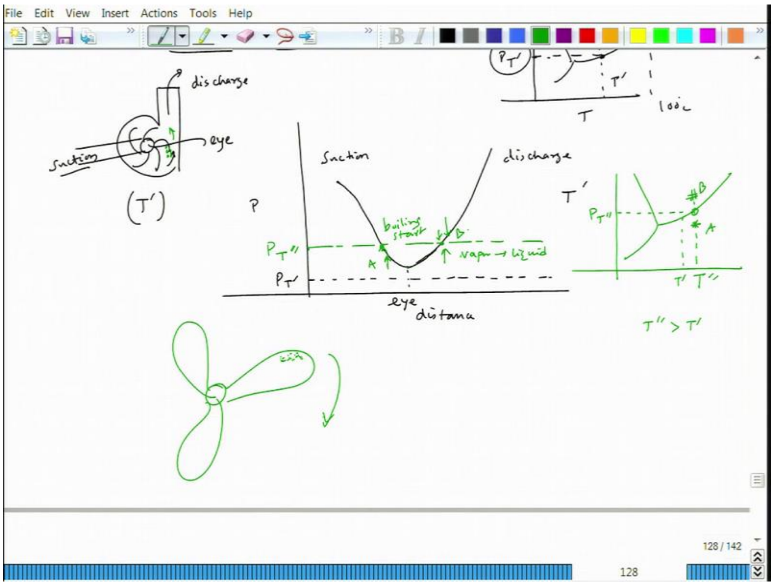

The in case of propeller you have a blade like this, this is a spindle. So, this is these are the blades and these are moving the back arm let us say this is the back of that. So, this portion will have lot of cavitation damage. And this propeller is basically taking a ship through the water, is not it. So, that because of this excessive beating down excessive cavitation damage the drag force the or the drag by which the steam is actually pushed forward will also reduce ok. So, this cavitation damage is a serious problem to this pump, impellers blades as well as propeller blades.

So, let me stop here. We will continue our discussion on cavitation and then we will start another special mode which is fretting mode. And then we will conclude erosion corrosion and then we will start another interesting topic which is called stress corrosion cracking. So, till then let me stop here.

Thank you.