New Spinning Technologies
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Lecture - 14
Yarn Formation Mechanism

Today, we are going to discuss Yarn Formation Mechanism on Air Jet Spinning. First, yarn formation basically means some kind of twisting arrangement has to be there. So, there has to be a twister.

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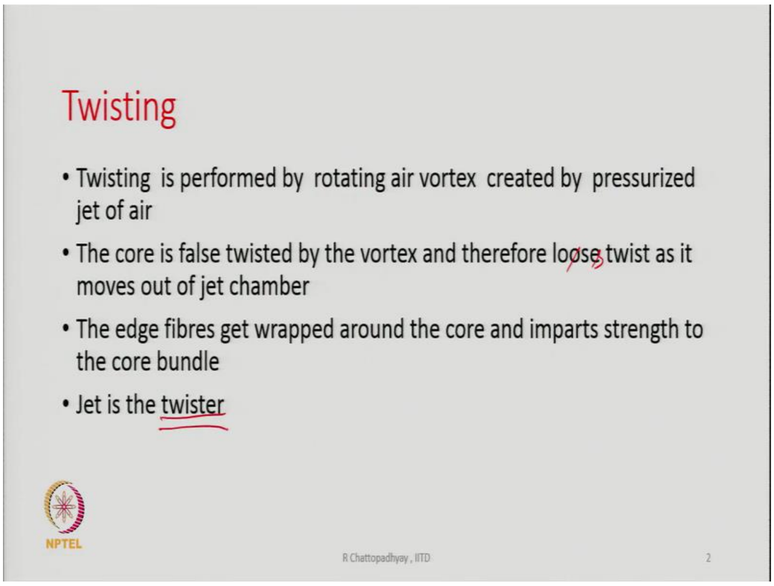

Now, here, the twisting is performed by a rotating air vortex and this vortex is created by pressurized jet of air. And hence, the name of the spinning system is also air jet spinning. The core part of the yarn is false twisted by the vortex and therefore, it loses twist as it moves out of the jet chamber. Since, any false twist will lead to you know nullifying the twist as soon as the yarn leaves the twisting element.

In this case, this is basically the air jet unit. But basically, it is generating false twist and that false twist is generating in the core part of the yarn. But, if it is generating false twist in the core part of the yarn, and the core is losing twist. That means, the fibres are becoming parallel again. In that case, the yarn will not have any strength at all. Therefore, there has to be some kind of wrapping twist on the core part of the yarn by some other fibres.

We have discussed about the principle of yarn formation earlier. So, we know that there are many edge fibres which are somehow escaping twisting actions because they are arriving from the edges of the twist angle which is there in the in front of the front roller nip. And these fibres ultimately will discuss more about them in details. These fibres are actually get wrapped.

They don't get twisted immediately. They escape twisting actions and they arrive late on the yarn core which is already false twisted. As a result of that, what happens, that these fibres will be finally, having some amount of wrapping on the core part of the yarn. We will come to know more about them as we go through the course. So, in this spinning system, jet is the twisting element. So, that is the twister.

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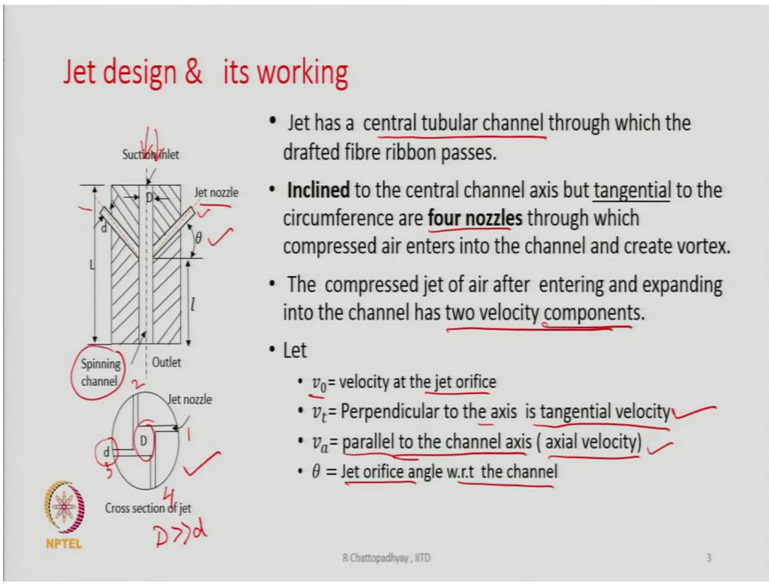

We should know more about how the jet is working, what is the construction of the jet and how does it work. So, here is a cross sectional view of the jet which is used in the spinning machine. So, what we see here is the cross sectional view. So, these are the jet nozzles. We are showing it only one single jet, though in the actual machine there will be two jets based one after the other.

Now, here are jet nozzles. The entire thing is jet housing and there is a central core part in the jet which is hollow. This jet has a central tubular channel through which the drafted fibre ribbon will pass. That means, if this is my the tubular channel, see this is the spinning channel, then fibres will enter from this side into the channel. So, this is this will be the fibre entry.

Now, inclined to the central channel axis, but tangential to the circumference are 4 nozzles. The cross sectional view of this jet housing is shown here, cross sections of the jet and we see there are four nozzles, nozzle 1, 2, 3 and 4. 4 nozzles are there and they are entering the housing at an angle. Angle with respect to the axis which is the central tubular channel through which the yarn will move.

So, they are inclined at a certain angle, but they are tangential to the circumference. And through these nozzles, what happens? The jet of air is basically injected. So, the compressed jet of air after entering the inlet part that is the spinning channel part that is shown here they will suddenly expand because the nozzle diameter is small d and the diameter of the central channel is capital D. And what we see here that capital D is much greater than small d.

So, once the air enters the channel, the volume increases and therefore, the air can suddenly expand. But because they are getting into the channel at an angle therefore, we will see that the velocity of the jet as it enters the channel, it is going to have two components. If v_0 is the velocity at the jet orifice that is at the entry point to the channel, then let us v_t become let us say the perpendicular to the axis and is a tangential velocity component.

And v_a is the is parallel to the channel axis and this is the axial velocity component. So, v_0 will have two components because the air is entering the main channel at an angle. So, it will have two components. One component perpendicular to the axis, the other component is parallel to the channel axis. So, one is called the axial velocity, the other one which is perpendicular is known as tangential velocity.

And theta is the jet orifice angle with respect to the channel. So, theta is shown here. The length is capital L, the length of the entire jet.

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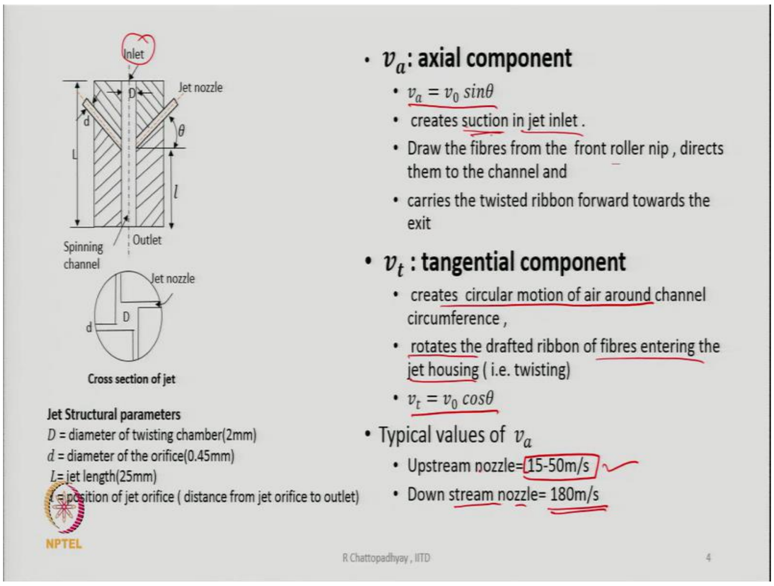

Therefore, the axial component is going to be v_a which is "$v_0 \sin\theta$", the axial component of the air which is entering the jet channel that is centrally located channel. So, this axial component will create suction in the jet inlet; that means, here at the inlet a suction will be generated there will be sudden drop in pressure because the air is moving forward with a certain velocity.

$$v_a = v_0 \sin\theta$$

And because the suction is created, this suction is going to draw the fibres from the front roller nip and directs them into the channel. So, from the front roller nip, the fibre will be able to enter into the channel because there is a negative pressure at the inlet of the channel. And after entering, this will move forward, because the air inside is moving forward towards the outlet.

The tangential component which is v_t that will actually create the circular motion and that will generate the vortex. So, vortex is generated by the tangential component of the velocity. And because the vortex is there vortex means the air is rotating at a very high velocity. And what it will do? It will catch the fibres and will try to also turn them, turn to rotate them.

So, the drafted ribbon of fibres, once they enter the housing they will be rotating because they are they get caught by the vortex. So, vortex will try to rotate them. And this will be the reason why the core fibres will be twisted. So, rotation to the bundle of fibres is given by the tangential component of the air that is injected inside the jet housing. And that tangential component is already written it is v_t is going to be "$v_0\cos\theta$".

$$v_t = v_0 \cos\theta$$

So, typical values of v_a, the axial velocity of the air that is passing through the central channel upstream the nozzle, it is around 15 to 50 ms^{-1}. And downstream the nozzle, it is around 180 ms^{-1}. These are some typical values. So, upstream side that is near the inlet, this is the velocity.

It will differ depending upon what is the air pressure, what is the inclination angle, what is the diameter of the jet nozzles. All of them will have some influence. But some typical values are like this that is upstream the nozzle it is 15 to 50 ms^{-1} and downstream the nozzle it can reach a velocity of 180 ms^{-1}, is quite high velocity.

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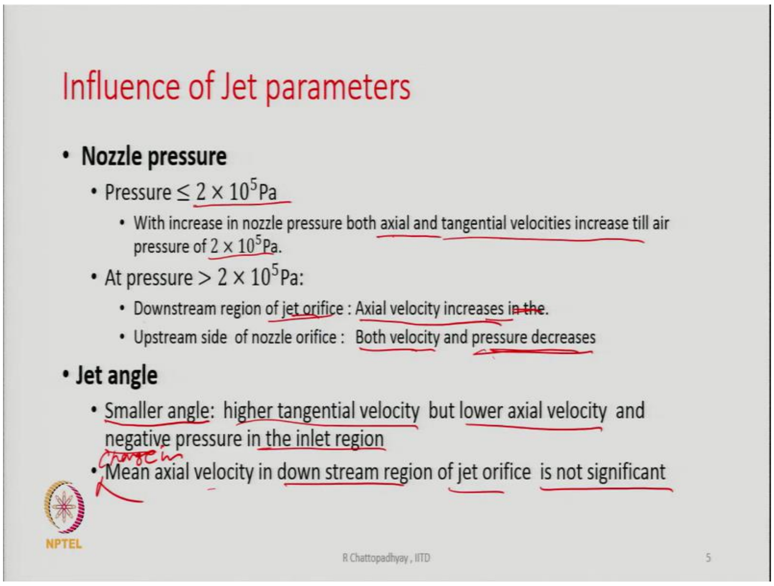

Now, influence of jet parameters. So, you will see that the jets have been designed in such a way that as soon as the air enters there is a vortex that is created which is going to twist the fibres. And at the same time the air is also driving the fibres you can say also the yarn towards the exit because there is axial component.

The nozzle pressure as long as it remains less than "2×10^5" pascal with increase in nozzle pressure both axial and tangential velocity increase, both of them will increase till the air pressure of “2×10^5” pascal. That has been shown by some researchers that as long as it remains “2×10^5” pascal or less in that range from let us say 1 to 0.5 to 1, 1 to 1.5, 1.5 to 2, the velocity both axial and tangential velocities is going to increase.

But when the pressure goes beyond “2×10^5” pascal, downstream the region of the jet orifice axial velocity increases continuously. On upstream side, both velocity and pressure decreases. This has been shown through simulations. By some researchers that beyond a certain velocity downstream side the axial velocity is going to increase. But upstream side of the nozzle orifice; that is at the inlet part basically both velocity and pressure is going to decrease.

If the pressure is going to decrease there, that basically mean the sucking capability is going to reduce and therefore, the fibres from the drafted strand that is from the front roller nip may not be able to quickly get in where inside the nozzle chamber. Because negative pressure is going to be less and less.

The other important parameter is the jet angle. Smaller angle gives you higher tangential velocity, but lower axial velocity and negative pressure in the inlet region. So, the angle is less angle could be 35°, 45°, in that range it could be 50°. So, different jet designs are there and the inclination angle of the jet or the jet orifice may vary between 35, 40, 45, 55 like that. So, smaller angle means higher tangential velocity, but lower axial velocity.

The other thing is the mean axial velocity in the downstream region of the jet orifice does not change much with reduction in or increase in jet angle. So, main axial velocity in the downstream region of the jet orifice does not change really significantly. So, you should write here that the change in mean axial velocity in the downstream region of the jet orifice is not really significant when we make the jet angle smaller.

So, these are the some of the studies which have been conducted by some researchers. And I am only giving you the very brief of the research results. This is what has been found and this is going to affect actually the quality of the yarn. So, you should need to know that what happens when pressure is increased or what happens if we change the jet design and go for a jet where inclination angles of the you know the nozzles are different.

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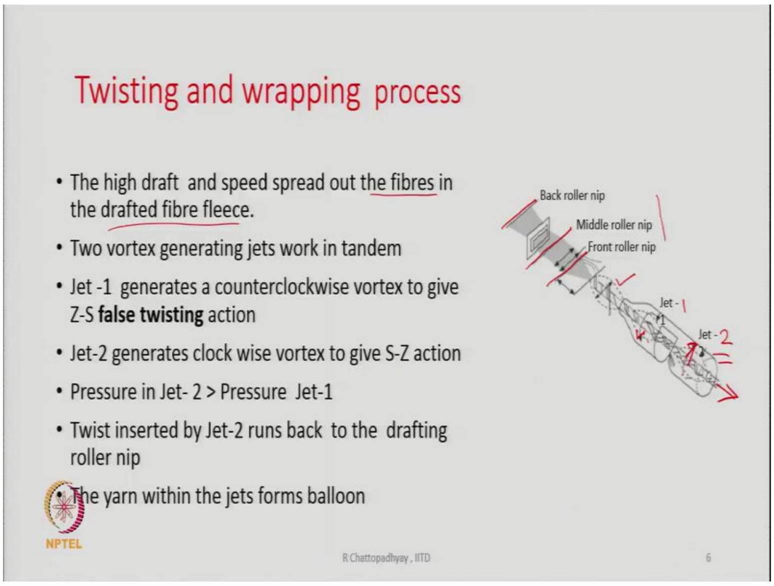

Now, twisting and wrapping process we want to look into it again. We all know that the high draft and speeds spread out the fibres in the drafted fibre fleece. Here we are showing you the drafting, drafted part of the sliver in this diagram. There is a back roller nip, middle roller nip line and this is the back roller nip line, this is the middle roller nip line, and this is the front roller nip line.

So, as soon as the draft is very high, (Refer Time: 18:18) tendency for the fibre to spread out. At the same time speed is also very high. So, spreading out is more. That means, the width of the twist angle is going to be larger. Now, two vortex generating jets they work in tandem, jet 1 and jet 2.

This is jet 1 and this is jet 2, two jets are working in tandem. Jet 1 generates counter clockwise vortex to give Z-S false twisting action. And jet 2 generates clockwise vortex to give S-Z actions. So, the two vortex are actually rotating in two different directions. So, vortex here you look at the arrow it is in this direction, and for this vortex the arrow is in the other directions.

So, the two jets with vortex and pressure in jet 2 is greater than pressure in jet 1. So, this jet, jet 2 is more powerful than jet 1. Twist inserted by jet 2 runs back to the drafting roller nip. So, jet 2 being more powerful as we twist the bundle, the bundle of fibres, the twisted twist will simply will propagate and will reach near the front roller nip. So, jet 2 is actually generating false twist also and being more powerful; whatever twists are generated by it will simply go reach the front roller nip.

The yarn within the jets form balloons. What we see here in this case is straight line. This is the direction which the yarn is withdrawal. But actually, the yarn within the jet is going to form a balloon. Like you see the balloon profile is shown here through dotted lines. So, within the chamber and outside also in front of the front roller nip, the small part of the yarn will be seen to create a balloon.

So, the yarn is within the jets actually following a spiral path. A rotational basically means if it forms a balloon that basically means it is basically rotating in a spiral path.

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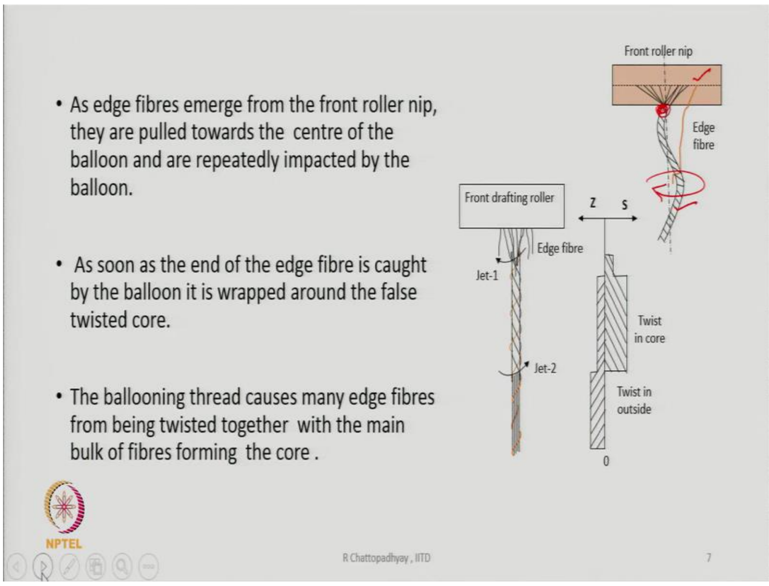

As edge fibres emerge from the front roller nip, let us say we are showing here 1 edge fibre, it has it is too far from the you know twist triangle. And therefore, it could not get caught by the apex point where the twist apex point or let us say the twist triangle. See, twist is reaching up to the point here.

At this point this fibre was not caught due to some reason because there could be lot of there place at the edge of the twist triangle because the air around the roller is also rotating violently and some fibres may simply be diverted and may not get caught immediately by the twisted yarn.

So, the edge fibres keeps on moving forward the forward end. The trailing end of the edge fibre is still under the nip of the front pair of rollers. So, they are positively gripped here, but the forward end is moving forward. And a time may come because the it is rotating in the form of a balloon, it will reach the surface of the balloon where the moment the yarn is there, the projecting out hairs of the yarn will be able to catch this fibre.

So, once this fibre end land on the balloon, there is a possibility that the fibre may get caught by the projecting hairs of the yarn. Not necessarily also, that the whenever it lands it will be caught. Maybe after landing also, it may not get caught for several times, but they may get caught also. So, whether they will get caught at the very first landing or not, there is lot of uncertainty.

But as soon as because they are moving forward and the fibre end is coming closer and closer to the balloon yarn, so at some point of time the projecting hair of the yarn will be able to catch it. The moment it is caught, this orange fibre that we see here as edge fibre will get wrapped, around the already twisted part of the yarn, because the already twist exists here. Now, this edge fibre cannot go inside the yarn, because the fibres are twisted already.

So, this fibre will remain on the surface and it will be simply wrapped around the main core part, core twisted core part of the yarn. That is what is going to happen to this fibre. So, the ballooning thread causes many edge fibres from being twisted together with the main bulk of fibres forming the core. So, ballooning is going to create some kind of air turbulence and therefore, also it will help in creating more edge fibres. And more and more edge fibres will get caught later by this balloon yarn.

And all those fibres which will be caught by the balloon yarn, they will be actually forming the wrapper fibres that we will see in the yarn.

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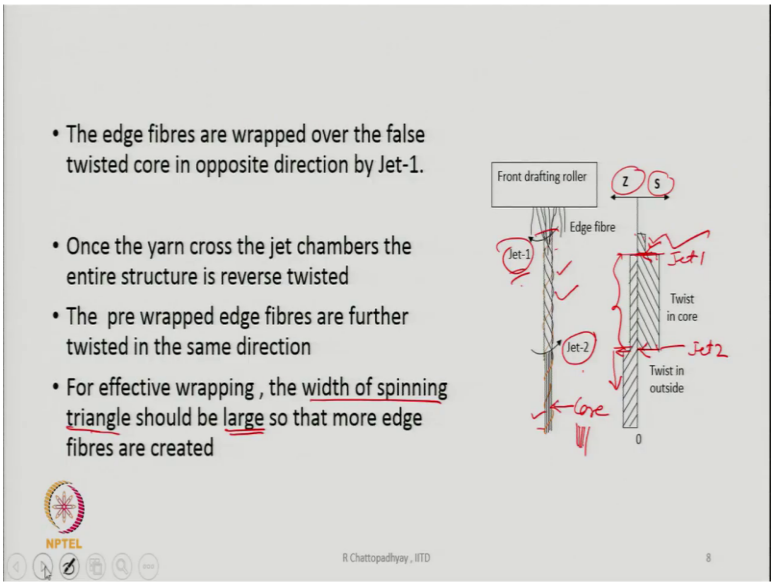

Now, in this diagram we see that the edge fibres are wrapped. Here we are showing you that this is jet 2 and this is jet 1 and in this region the orange color is indicating a fibres which is already wrapped. And this fibre wrapping is you see in a different direction than the helix angle that we see in the yarn because jet 1 rotates in opposite direction then jet 2.

The vortex created by jet 1 is rotating in opposite direction than the vortex created in jet 2. Therefore, the wrapping directions of the edge fibres because of jet 1, jet 1 is going to pre-wrap the fibres. And they will be able to pre-wrap the fibres to some extent. And therefore, this orange color fibre that we see it is getting pre-wrapped by the vortex generated by jet 1.

As I said earlier also that if there is only one jet, then also the yarn will be formed. But that yarn is not going to be very very strong because even then some edge fibres will get caught by the balloon yarn and they will be twisted or wrapped to some extent. And when the entire core is going to lose twist this fibres edge fibres will be wrapped now in the opposite directions because of the false twist that the main core has received.

So, with single jet also you will able to form some yarn, but that yarn is going to be not so strong. So, to enhance strength, jet 1 exist and it is trying to pre-wrap the edge fibres around the core of the yarn. So, and once the fibres or the yarn cross the entire jet chamber that is the go move out of the jet 2.

All the fibres in the core they are parallel to each other, because the entire core is going to lose twist, because core part is false twisted by jet 2. So, they will lose twist as they become parallel fibres. But now because entire core is rotating in the opposite direction and losing twist, they will cause the pre-wrapped edge fibres to be wrapped much more tightly now. Because these edge fibres will now receive more twisting torque and will get wrapped much more tightly around the core part of the yarn.

So, the twist variation from here to here is shown in this diagram. Twist in the core if you see from here to there, one is S twist direction, this is Z twist direction. So, what we will see? If you look at this diagram from here to there where jet 1, this corresponding to jet 1 and this region corresponding to jet 2.

So, up to jet 1 we see the twist is little less in the core because the jet 1 is trying to rotate the core also in the opposite directions. So, from here to there twist in the core is quite high, all depends upon the power of jet 2 and as the twist propagates towards the front roller nip. Jet 1 has got some influence on the twist of the twist that is present in the core.

So, because jet 1 is rotating in the opposite direction; jet 1 is not rotating sorry it is the vortex created by jet 1 is rotating on the opposite direction. So, there is little loss of twist and therefore, twist in here there is a drop in twist. But still twist is still there twist is still there in the same edge directions, only bit little less.

Whereas, in the from here to there, the twist of the edge fibres they are shown, twist of the edge fibres are in the opposite direction that is in the Z directions because they have been pre-wrapped by jet 1. And once the yarn goes beyond jet 2, further down, the pre-wrapped twist is going to increase. So, there is a step jump from here to there and increase in twist.

Whereas, twist in the core becomes now 0, there is no twist. So, there is a drop here. There is no twist in the core because the core was initially false twisted. So, that is what is going to happen; that the ultimately the core will be having nil twist or 0 twist. And we will get quite you know a some percentage of wrapper fibres which are basically because of the generation of edge fibres of the in the twist angle they will be wrapped around the core and that is what is going to give or impart strength to the yarn.

So, for effective wrapping, what is important? The width of the spinning triangle should be large, so that we can generate more edge fibres. That is why twist angle has to be as large as possible in this case. If we want 15, 20 percent fibres to be wrapping, the core part of the yarn, then the twist angle has to be large.

So, high draft actually helps in generating lot of it increases the width of the twist angle therefore, more edge fibres. But at the same time, we have to remember that there is a limit to the generation of edge fibres and limit to the proportion of fibres which is going to wrap the core part of the yarn, and at the same time giving you adequate strength.

We will discuss about the structure part and the property part of the yarn in the coming lectures. So, we will discuss more about that what is the optimum percentage of wrapping fibres in the air jet yarn.

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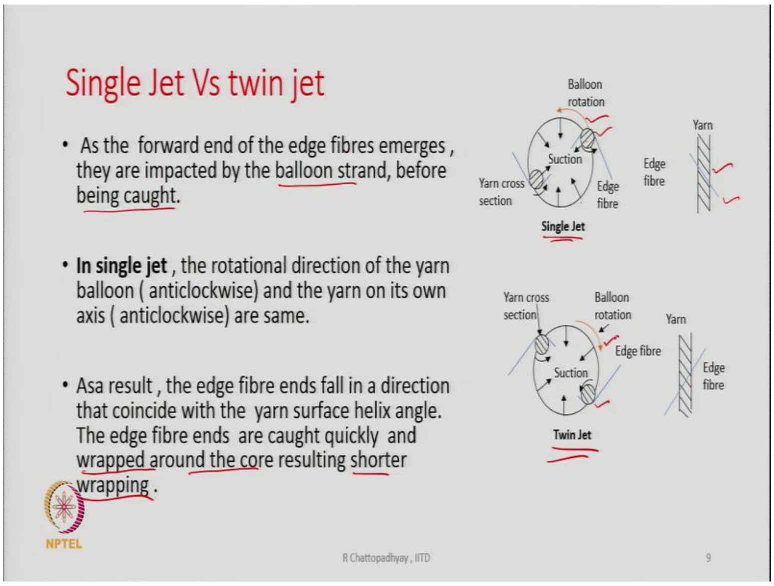

Now, single versus twin jet we have discussed a bit about them; that in, single jet also we can form yarn, but as I said earlier that the yarn will be weaker. Whereas, if we go for twin jets, two jets, one after the other, the yarn is going to be stronger. The other important aspect of single versus twin jet is that as the forward end of the edge fibre emerges, they are impacted by the balloon strand before they get caught.

So, here is the diagram with single jet. And what is special about in this diagram? Is that this circle indicates the rotation of the balloon shown by this orange arrow. And this is a suppose, this is the circle in which the balloon is rotating. And the yarn cross section is shown here. And in this case, when there is a single jet the rotational direction of the balloon formed by this false twisted yarn, and the rotational direction of the yarn on its own axis, both are same.

So, if we see it here the rotational direction of the balloon is anticlockwise, the rotational direction of the yarn is also anticlockwise, so both are same. Now, when both are same then what happens? That when edge fibre lands on the yarn, the edge fibre is shown by this blue line. When the edge fibre will land on this yarn, the direction of the edge fibres and the helix angle of the yarn twist they are perfectly matching or coinciding. When they match and coincide together, they get caught very easily because they are matching.

In this case capturing of the edge fibres became easier. And as a result, the wrapping length around the core becomes shorter. So, the fibre will be wrapped around over a shorter length of the yarn. Even though fibre is long because the moment it will as they get caught, therefore the actual length of the fibre which will be wrapping the core will be shorter.

And what is the implication of that? The implication is that the wrapping twist is going to be over a shorter length of the yarn. And as a result, the yarn is going to be weaker. So, for a given edge fibres; that means, every edge fibre has a possibility that the leading part of the edge fibres will form wrap around the core part of the yarn and the rest part of the fibre may be forming the core.

So, the same fibre will see that part of it is forming the core and part of it is forming the wrapper. And the wrapping part will be less if we use single jet and therefore, the yarn will be weaker. In the case of twin jets, when twin two jets are used in that case the rotational direction of the yarn and rotational direction of the balloon, what we see here? That, they are not same. This is the difference that we will get.

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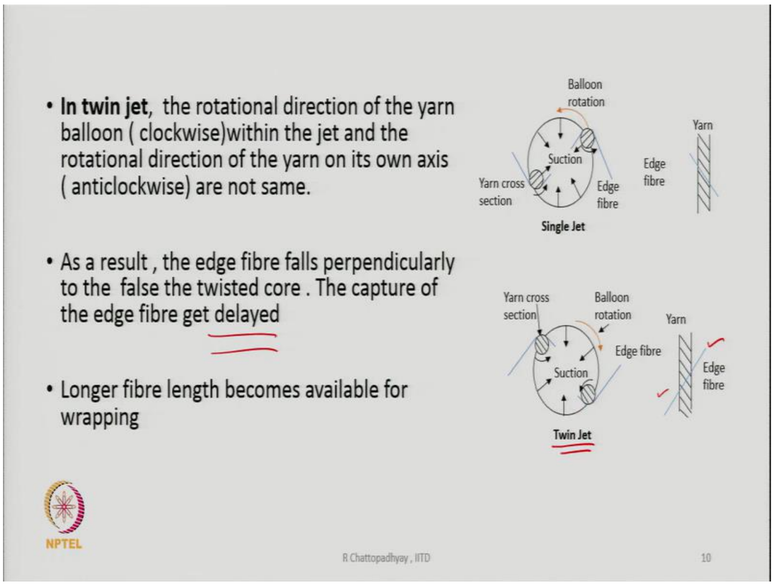

In this case, this is twin jet case, they are rotating in the clockwise directions, the balloon rotates in the clockwise directions, but the yarn is rotating in the anti-clockwise direction. So, as a result, the edge fibre will arrive on the yarn at an angle which will not match the helix angle of the false twisted core.

So, the implication is that this edge fibre which is landing on the yarn surface, they will miss getting caught by the projecting fibres which are there on the surface of the yarn. So, the capture of the edge fibres will be finally, delayed. So, the length that you will be projecting out from the front roller nip, the length of the edge fibre which we will projecting out from the front roller nip will be longer when they get caught.

So, initially, even though it is coming in contact with the balloon, it may not get caught. So, there will be lot of you know, even though it is trying to hit the balloon is trying to hit the edge fibres and they are coming into contact, but still they may not get caught immediately. So, the there the catching of the fibre is going to be delayed.

And as a result of the delay, what is the benefit we will get? That, longer length of edge fibres will be available for getting caught subsequently. And in the long length of the fibre is available for getting caught subsequently. The this long length will be able to be capable to wrap a longer length of the yarn. So, the wrapping length of the yarn is going to be larger because long length of the fibre, the forward end of the fibre is available for wrapping. That is the benefit we will get.

And this is happening because the landing direction is such that the inclination angle of the fibre and the inclination angle of the helix angle of the yarn, they are mismatching, they are not coinciding. So, that is the benefit we will get. Therefore, in twin jets also we will get long wraps. Whereas, in the case of single jet we will find shorter wraps. So, long wraps will give you more strength to the yarn than shorter wraps. That is the benefit we will get.

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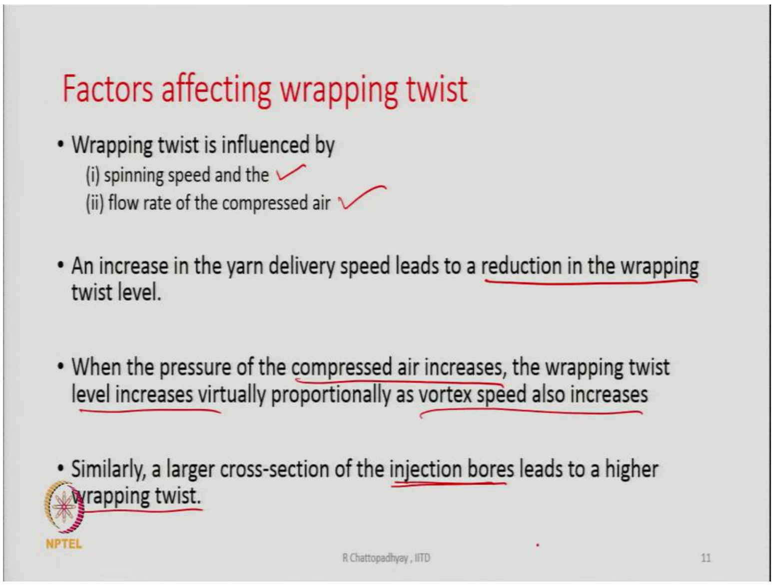

Now, factors affecting wrapping twist. Wrapping twist will be influenced by two things, one is spinning speed or delivery speed and flow rate of the compressed air. This compressed air is going to decide the vortex speed. And increase in the yarn delivery speed leads to reduction in wrapping. Whatever that the speed of the vortex, the rotational speed of the yarn is much less than that.

So, there is a slippage. Between the speed of the vortex and the speed of the yarn if we compare, there are lot of slippage is there. If we increase the delivery speed, whatever speed at which the vortex is capable to rotate the yarn that remains fixed. And the delivery rate increases, the wrapping twist will decrease.

And that may have influence on the strength of the yarn. But whenever the pressure of the compressed air is increased wrapping twist will level will increase because the vortex speed is going to be more that is the benefit of going to increase the pressure. But as I said very high pressure may create some other problem also.

A larger cross section of the injection bores leads to higher wrapping twist. This is also we should know that a larger cross section of the injection bores can lead to higher wrapping twist. And with this we close this discussion on twisting part of the air jet yarn. So, the air jet yarns are twisted by the vortex that is generated by the two jets that we use. Two jets are used in succession, whereas jet 2 which is away from the front roller that is more powerful and the jet which is closer to the front roller are less powerful.

Jet 1 which is less powerful is supposed to pre-wrap the fibres in advance in opposite directions. Whereas, purpose of jet 2 is to false twist the core and; so, that even though the total twists are removed the wrapping twist of the edge fibres will be sufficient enough to impart strength to the core part of the yarn.

So, that is what is you know happening in this case and because the vortex speeds are very very high; and they cannot be really measuring the vortex speed is difficult. But the speed of the yarn is not you know close to the speed of the vortex, there is lot of slippage between the yarn and the vortex.

So, yarn rotates on its own axis at a much lesser speed. But even that speed is much much higher than what we get you know the speed of yarn, rotational speed of yarn in ring spinning or even maybe in rotor spinning also. Speeds being very high, the twisting rate becomes very very high and therefore, our production rate also increases.

So, with this we close today’s discussion.

Thank you.