Aerodynamic Design of Axial Flow Compressors & Fans
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Lecture 40
Design Low Speed Compressor (Contd.)

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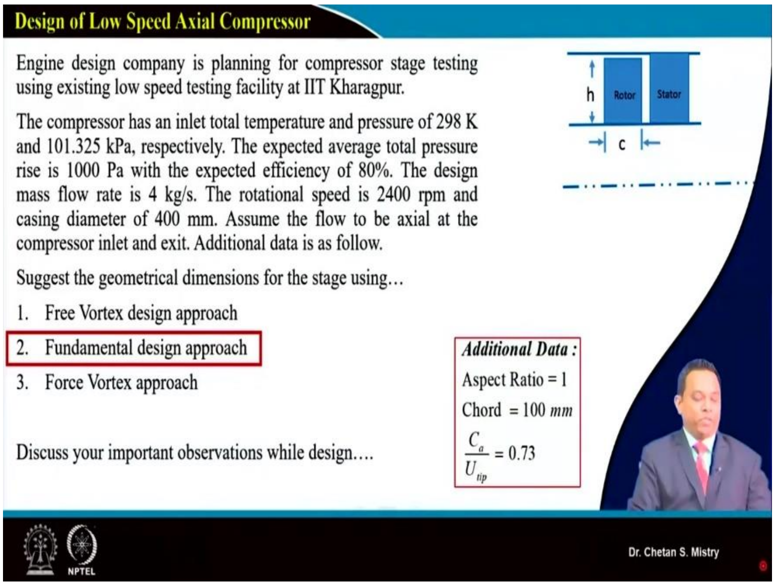

Hello, and welcome to lecture 40. We are discussing design of low speed axial flow compressor. In last lecture, we were discussing about design of low speed compressor for given data using free vortex concept. So, in today’s lecture we will be discussing using the fundamental design approach.

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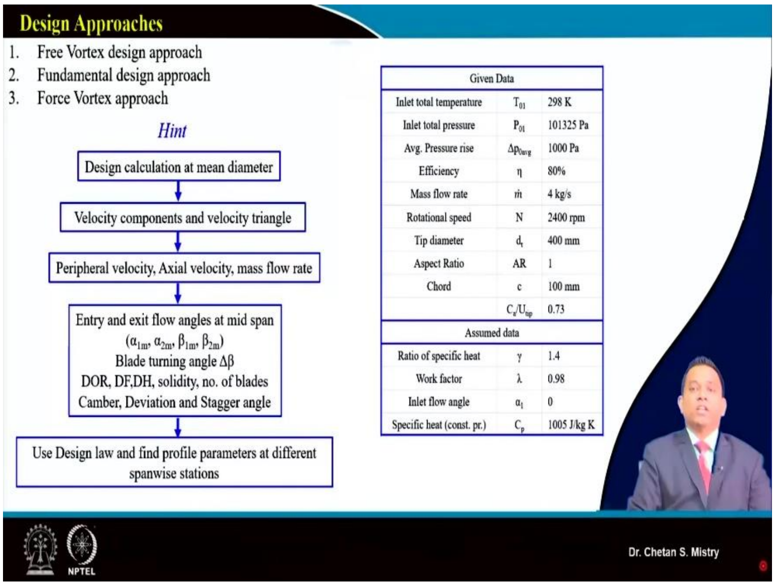

So, what all we have discussed in earlier class; our calculation that's what we will be starting with the mean diameter. So, all parameters we are calculating at the mid station. So, once fundamentally we learn, we are doing our calculation at the mid station, say especially for low speed axial flow compressor, we are considering our mid station as 50% of the span, okay. So, based on our understanding, we will be doing all our parametric calculation and after that we will be applying our design approach. So, let us see what all we have done in sense of say mid span calculation.

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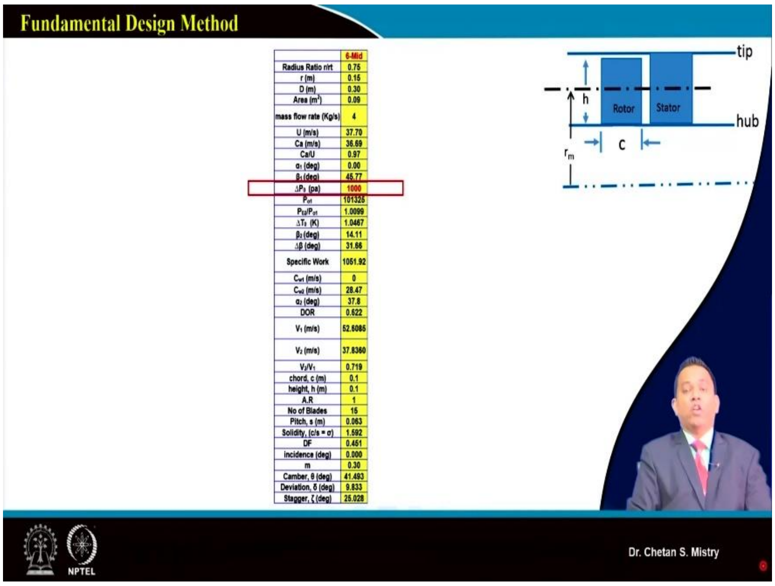

So, we will not be discussing again like what all we have done at mid span calculation. So, if you recall, when we were discussing say design using free vortex concept, we have made this mid-section design calculation. So, here if you look at for this fundamental approach also at mid station, we are considering our say pressure rise ΔP_0 at mid station to be say 1000 Pa and this is what is all data what we have considered with.

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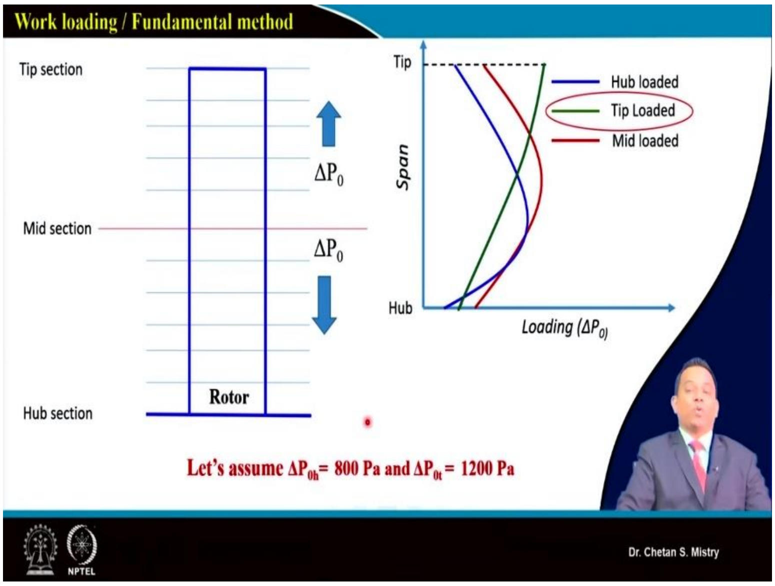

Now, this approach, if you recall when we were discussing different design approaches that time we have discussed there is a flexibility in sense of varying by ΔP_0. So, my ΔP_0 I can distribute in a way like if you look at here this is what is say hub loaded configuration; say…this is what is say mid-loaded configuration and third if you look at, this is what is representing tip loaded configuration.

So, here in this case, at mid station we will be doing all our calculation and we will be assuming our ΔP_0 at hub and we will be exiting our ΔP_0 at the tip station. And, then after this ΔP_0 we will be dividing in 11 stations, say 5 station below my mid span and 5 station above my mid span such a way that, that will be giving me uniform distribution of what all parameter we are targeting. Mainly, when we are saying our parameters, we are more interested in sense of blade angles.

Because if we will be having say uneven variation of blade angle that may lead to make the blade to be zigzag. So, we will see what all we need to take care of when we are doing the design using this fundamental approach, okay. So, this is what is all we need to start with. So, at mid station we already have done our design. So, let us move here in this case, let us assume say at hub, we will be considering our pressure to be 800 Pa and at the tip we are considering our pressure to be 1200 Pa and at mid station we have done calculation for 1000 Pa, okay. So, at hub and tip we need to do our calculation.

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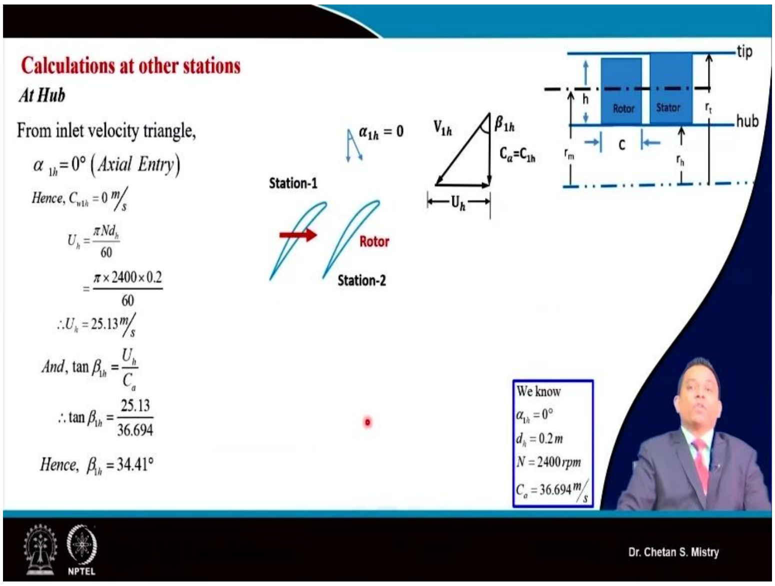

So, here if you look at, let us start with the calculation at the hub. So, this design approach, that's what is different from what we have discussed for free vortex design. So, here what all we need to do is we need to do our calculation at the hub station in sense of flow angles, okay.

So, suppose if I consider, this is what will be my velocity triangle at the hub, you can say my U_{hub}. So, U_{hub} we can calculate based on a

$$U_h = \frac{\pi N d_h}{60}$$

$$= \frac{\pi \times 2400 \times 0.2}{60}$$

$$\therefore U_h = 25.13\ m/s$$

Since my hub diameter, that's what is say 0.2 we can do that calculation. Same way at hub, we can do our calculation for β_1. So, this β_1 at the hub, that's what is given by U_h/C_a. Since our peripheral speed at the hub it is known, we are assuming our axial velocity to be constant throughout my span. That is the reason this is what all we have already calculate with, it is say 36.69 m/s. And, that's what will be giving me my β_1 as say 34.41 at the hub.

$$And, \tan\beta_{1h} = \frac{U_h}{C_a}$$

$$\therefore \tan\beta_{1h} = \frac{25.13}{36.694}$$

$$Hence, \beta_{1h} = 34.41°$$

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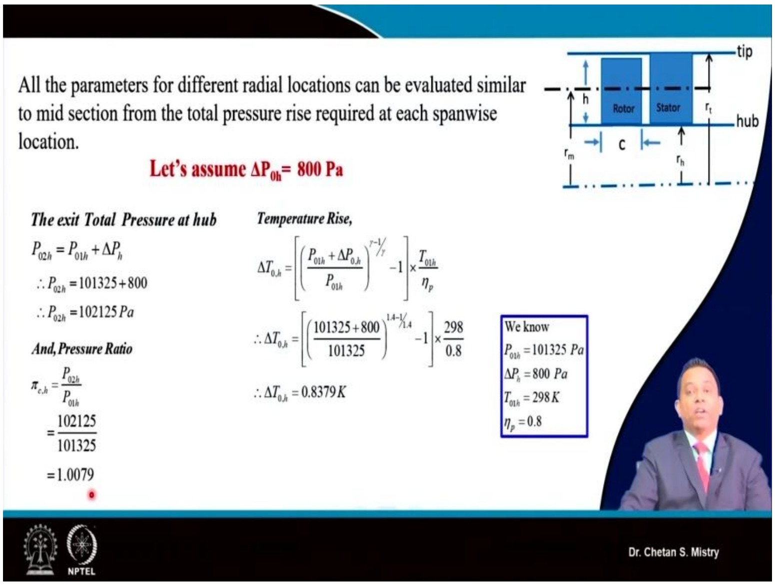

Now, what is my next required parameter, that's what is say my β_2. So, here in this case, when we are looking for the calculation for β_2, we need to compare our aerodynamic work and thermodynamic work; the way in which we have done calculation for the mid station. So, in order to do that calculation, what we have assumed? Say, we have assumed our ΔP_0 at hub to be 800 Pa. So, if this is what is your case, you can calculate my P_0 at the hub, that's what is say $P_{01h} + \Delta P_{0h}$, that's what is coming say 102.125 kPa, okay.

$$P_{02h} = P_{01h} + \Delta P_h$$

$$\therefore P_{02h} = 101325 + 800$$

$$\therefore P_{02h} = 102125\ Pa$$

So, based on this calculation, we can do calculation for the pressure ratio at the hub, that's what is coming 1.0079, okay.

$$And, Pressure\ Ratio$$

$$\pi_{c,h} = \frac{P_{02h}}{P_{01h}}$$

$$= \frac{102125}{101325}$$

$$= 1.0079$$

So, this approach, that's what is somewhat different compared to what all we have discussed in earlier case. Now, once this is what is known to me, we can calculate our ΔT_0 at the hub based on our fundamental equation. Since our efficiency it is given 80%, so, we can write down this number say we are assuming our T_{01} at the hub to be 298 only. So, that's what is giving my ΔT_0 at the hub as say 0.83, okay.

$$Temperature\ Rise,$$

$$\Delta T_{0,h} = \left[\left(\frac{P_{01h} + \Delta P_{0,h}}{P_{01h}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \times \frac{T_{01h}}{\eta_p}$$

$$\therefore \Delta T_{0,h} = \left[\left(\frac{101325 + 800}{101325}\right)^{\frac{1.4-1}{1.4}} - 1\right] \times \frac{298}{0.8}$$

$$\therefore \Delta T_{0,h} = 0.8379\ K$$

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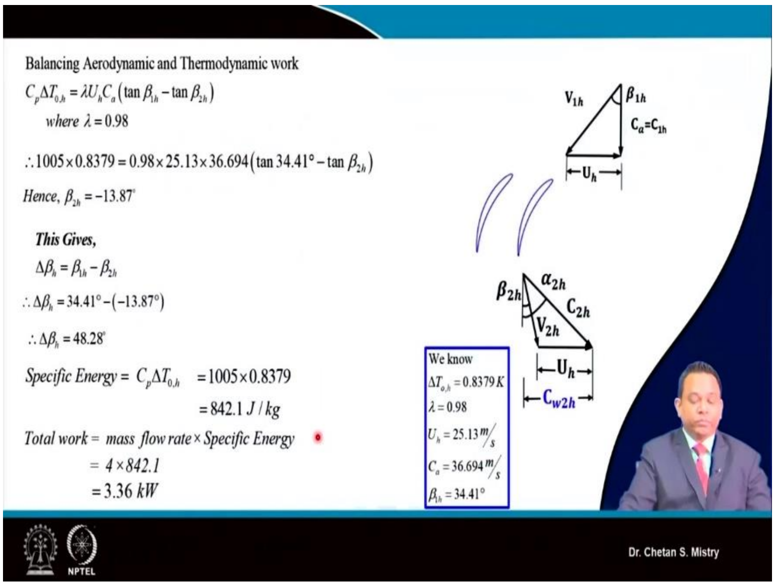

Now, once this is what is known to us, then we can do our calculation for the blade angle or we can say relative flow angle at the exit of our rotor. So, what we can do? We can compare our thermodynamic work and aerodynamic work; our work done factor, that's what we have assumed to be 0.98. If we are putting this number, that's what is giving me my β_2 at the hub to be -13.87.

$Balancing\ Aerodynamic\ and\ Thermodynamic\ work,$

$$C_p \Delta T_{0,h} = \lambda U_h C_a (\tan\beta_{1h} - \tan\beta_{2h})$$

$$where, \lambda = 0.98$$

$$\therefore 1005 \times 0.8379 = 0.98 \times 25.13 \times 36.694 (\tan 34.41° - \tan\beta_{2h})$$

$$Hence, \beta_{2h} = -13.87°$$

So, be careful, when we are doing our calculation accordingly you need to modify your velocity triangle, okay. So, here if you look at, this is what is my velocity triangle at the entry, and this is what will be my velocity triangle at the exit of my rotor.

So, here you can see this is what is representing, my β_2 at the hub to be -13.87, okay. Now, what we know? We can calculate our $\Delta\beta$ based on what parameters say β_1 and β_2, that's what is known to us, that's what is giving me my $\Delta\beta$ at the hub to be 48.28°, okay.

Now, same way we have done calculations for the specific energy. We can write down, say that's what is given by $C_p \Delta T_0$. We can do our calculation, it says this is what is coming 842.1 J/kg.

$$Specific\ Energy = C_p \Delta T_{0,h} = 1005 \times 0.8379$$

$$= 842.1\ J/kg$$

We can calculate what will be our total work requirement at the hub station. Here in this case, we need to be really careful of what parameters we are calculating because my ΔT_0 at the hub, it is different; my ΔT_0 at the mid, it is different; my ΔT_0 at the tip, that's what is different.

And, that is the reason why my total work that also is varying along my radius or we can say that's what is varying along my span. So, basically, when we are calculating this total work done at different station, we will be averaging out date and that's what will be giving us what power that's what is required. We will see what is the difference in sense of power when you are using your free vortex concept and when you are using your fundamental concept, but this is what is a way in which we are calculating our total work done.

$$Total\ work = mass\ flow\ rate \times Specific\ Energy$$

$$= 4 \times 842.1$$

$$= 3.36\ kW$$

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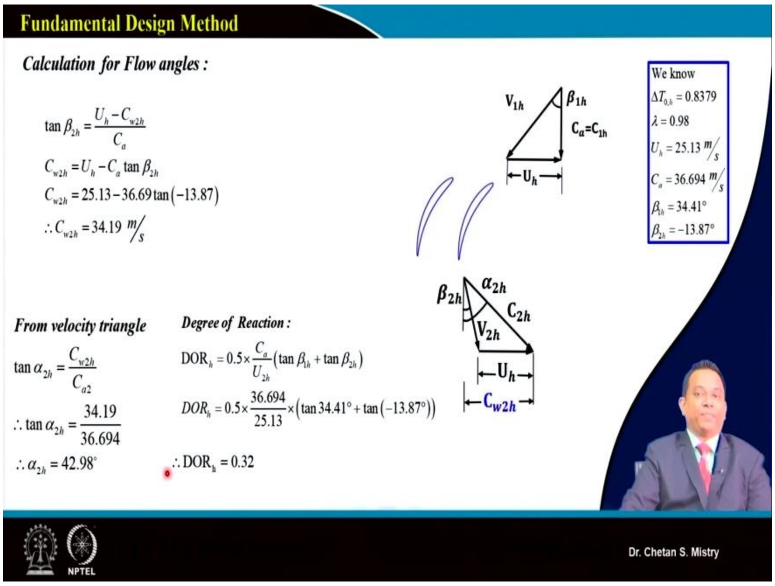

Now, once we have calculated that part, we can do our calculation about say what will be my say whirl velocity component. So, what we know? From our velocity triangle, just write down this carefully, it says this is what we are writing in sense of say different formulation, that's what is giving me my C_{w2}, that's what is equal to 34.19 m/s, okay.

$$\tan\beta_{2,h} = \frac{U_h - C_{w2h}}{C_a}$$

$$\therefore C_{w2h} = U_h - C_a \tan\beta_{2h}$$

$$\therefore C_{w2h} = 25.13 - 36.69\tan(-13.87°)$$

$$\therefore C_{w2h} = 34.19\ m/s$$

Now, once you have calculated what is our C_{w2}, we can calculate what our α_2 is and this is what is giving me 42.98° degree.

$From\ velocity\ triangle,$

$$\tan\alpha_{2h} = \frac{C_{w2h}}{C_{a2}}$$

$$\therefore \tan\alpha_{2h} = \frac{34.19}{36.694}$$

$$\therefore \alpha_{2h} = 42.98°$$

Since, my β_1 and β_2 that's what is known to me, my $C_a/U_{hub},$ that's also known to me, we can calculate what will be our degree of reaction at the hub and if you are putting this number, it says our degree of reaction, that's what is coming 0.32. So, we can understand degree of reaction at the hub it is coming 0.32, that's what is a reasonable number in sense, okay.

$Degree\ of\ Reaction,$

$$DOR_h = 0.5 \times \frac{C_a}{U_{2h}}(\tan\beta_{1h} + \tan\beta_{2h})$$

$$\therefore DOR_h = 0.5 \times \frac{36.694}{25.13}(\tan 34.41° + \tan(-13.87°))$$

$$\therefore DOR_h = 0.32$$

So, this is what we can say fine, okay. Now, careful here, suppose say my degree of reaction at the hub is coming negative then we are having problem. What we need to do? We need to do our re-calculation, that's what we will be starting from what P_0 what we have assume… ΔP_0. You need to adjust that number in such a way that my degree of reaction at the hub that will be coming more than 0 or that will be coming positive number. Remember this part, okay! So, what assumption we have made, 800 Pa, you can assume 500 also, even you can assume 400. But you need to be very careful when you are doing your calculation, your degree of reaction, that's what is the first cut check, okay. It should not come negative, it should not come 0, okay.

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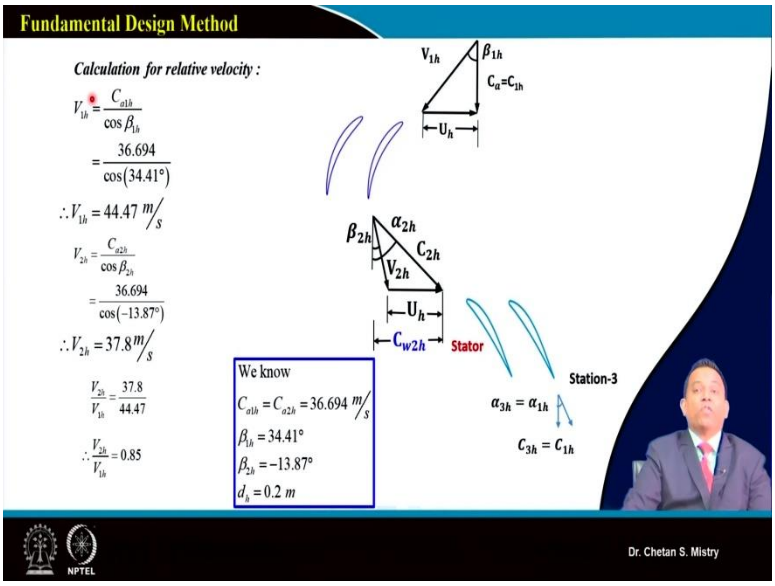

Now, once this degree of reaction, that's what is known to us, we can do same calculation in sense of our De-Haller's number or relative velocity ratio. So, if you are putting this in the formulation. So, V_{1h}, that's what we can write down in sense of cos component and it says this is what is coming, 44.47 m/s.

$$Calculation\ for\ relative\ velocity,$$

$$V_{1h} = \frac{C_{a1h}}{\cos\beta_{1h}}$$

$$= \frac{36.694}{\cos(34.41°)}$$

$$\therefore V_{1h} = 44.47\ m/s$$

Same way here in this case, we can do our calculation at the exit. So, this V_{2h}, that's what is coming in sense of $\frac{C_a}{\cos\beta}$ and that's what is coming to be say 37.8.

$$V_{2h} = \frac{C_{a2h}}{\cos\beta_{2h}}$$

$$= \frac{36.694}{\cos(-13.87°)}$$

$$\therefore V_{2h} = 37.8\ m/s$$

Now, we are having this number, we can understand, we are looking for say diffusion. So, our De-Haller's number, that should come more than 0.72 and here if you look at this is what is coming 0.85. So, we can say we are in a safe range, okay.

$$\frac{V_{2h}}{V_{1h}} = \frac{37.8}{44.47}$$

$$\therefore \frac{V_{2h}}{V_{1h}} = 0.85$$

Suppose say, this is also not coming then again you need to go with the iteration for assuming our ΔP_0, okay. So, this is what is little iterative. So, you know, in sense of making this numerical simple for understanding with more complexity, we have assumed this number, okay.

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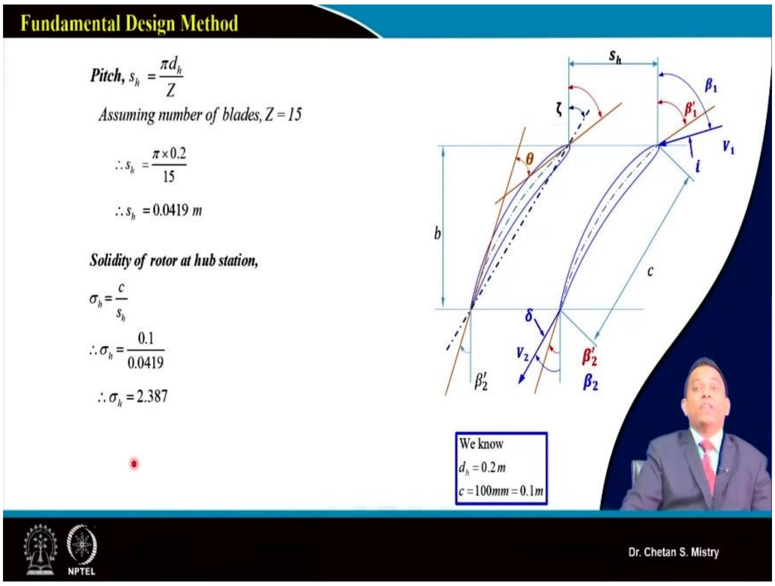

Now, once we have done our calculation, our next parameter we are targeting that's what is my diffusing factor. And in order to do the calculation for the diffusion factor, we need to calculate what will be the solidity, okay. Now, for calculation of solidity, we need to check with pitch and chord. So, it says pitch, we can say that's what is $\frac{\pi d_h}{Z}$, my hub diameter, that's what is known to be very careful, we are doing our calculation at the hub station, that is the reason do not forget you need to put hub diameter. Now, in order to avoid the confusion at this moment, what numbers we have assume for free vortex, same number we are considering. So, for this case, our number of rotor blades we are assuming to be 15.

So, it is possible for us to do one to one comparison. No one is stopping you to change his number of blades, again. So, here we are considering this to be say 15. So, if you are putting this as a number, we can calculate our pitch and that's what is coming 0.0419 meter and my solidity that's what is coming 2.387, okay.

$$Pitch, s_h = \frac{\pi d_h}{Z}$$

$$Assuming\ number\ of\ blades, Z = 15$$

$$\therefore s_h = \frac{\pi \times 0.2}{15}$$

$$\therefore s_h = 0.0419\ m$$

$$Solidity\ of\ rotor\ at\ hub\ station,$$

$$\sigma_h = \frac{c}{s_h}$$

$$\therefore \sigma_h = \frac{0.1}{0.0419}$$

$$\therefore \sigma_h = 2.387$$

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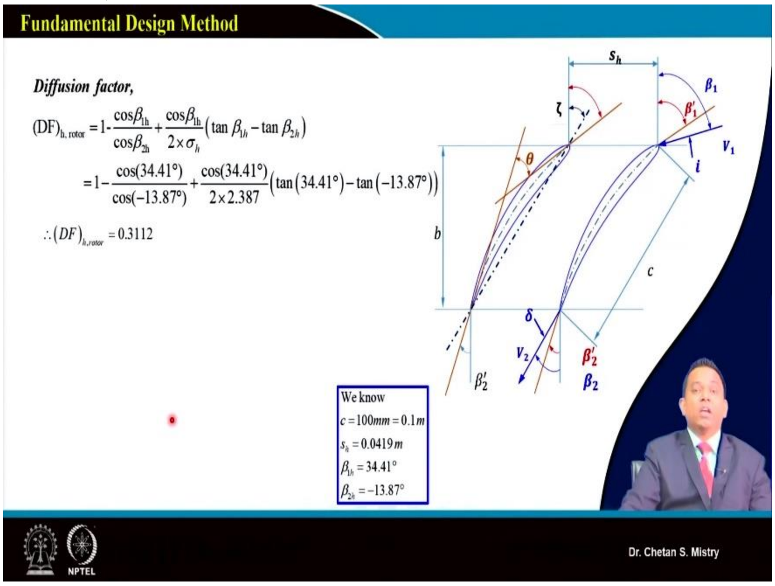

So, if this is what is known to us at hub station, we can do calculation for the diffusion factor. And as we have discussed when we are talking about say rotor for diffusion factor calculation, we are considering these angles to be β_1 and β_2. Very careful what all we are writing, that's what is at the hub station. And it says at the hub, we are getting our diffusion factor to be 0.31, we can say this is also in a reasonable range, you can say this is what is okay with. So, we have done our calculation for degree of reaction, we have checked with relative velocity ratio, we have checked with the diffusion factor. So, what number 800 Pa pressure what we have assume at the hub, it seems to be okay with us.

$Diffusion\ factor,$

$$(DF)_{h,rotor} = 1 - \frac{\cos\beta_{1h}}{\cos\beta_{2h}} + \frac{\cos\beta_{1h}}{2 \times \sigma_h}(\tan\beta_{1h} - \tan\beta_{2h})$$

$$= 1 - \frac{\cos(34.41°)}{\cos(-13.87°)} + \frac{\cos(34.41°)}{2 \times 2.387}(\tan(34.41°) - \tan(-13.87°))$$

$$\therefore (DF)_{h,rotor} = 0.3112$$

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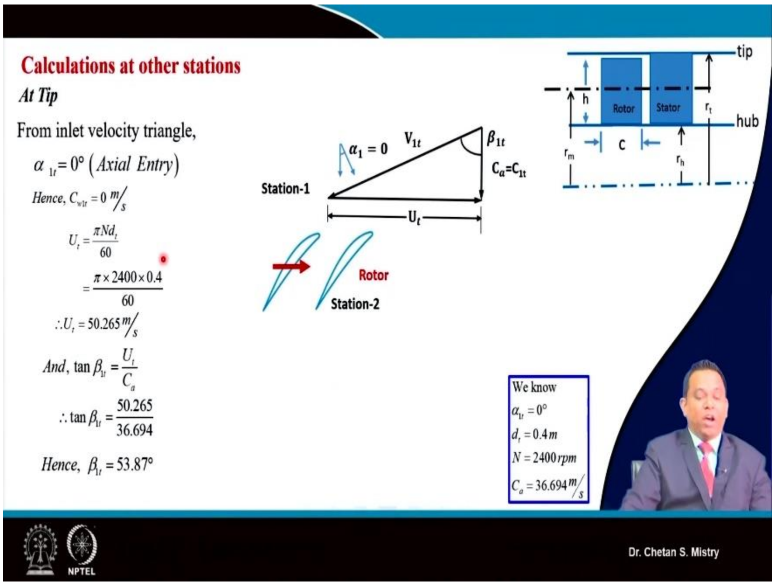

Now, once we have done the calculation for the hub, we need to check at the tip also. So, for the calculation at the tip, this is what we can say my α_1 at the tip that's what is 0. We can do our calculation for the peripheral speed at the tip, that's what is given by $\frac{\pi d_t N}{60}$. My tip diameter at this moment we are considering 0.4 meter. So, that's what is giving my U_{tip} to be 50.26 m/s, okay.

$$At\ Tip,$$

$$From\ inlet\ velocity\ triangle,$$

$$\alpha_{1t} = 0° \ (Axial\ Entry)$$

$$Hence, C_{w1t} = 0\ m/s$$

$$U_t = \frac{\pi N d_t}{60}$$

$$= \pi \times 2400 \times \frac{0.4}{60}$$

$$\therefore U_t = 50.265\ m/s$$

And we can calculate what will be our β_1 at the tip based on the velocity triangle; at β_1 at the tip, that's what is coming 53.87°, okay. Inline to what we have done calculation for the hub station, same way we can go with the calculation at the tip station.

$$And, \tan\beta_{1t} = \frac{U_t}{C_a}$$

$$\therefore \tan\beta_{1t} = 50.265/36.694$$

$$Hence, \beta_{1t} = 53.87°$$

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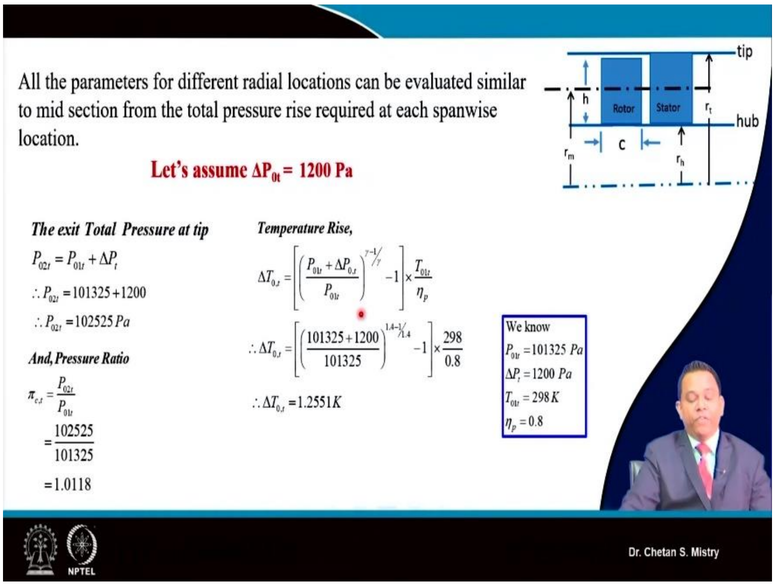

So, what we will be doing? We have our ΔP_0 at the tip, we have assumed at this moment to be say 1200 Pa, okay.

$$Let's assume\ \Delta P_{0t} = 1200\ Pa$$

So, if we are putting that it says we can calculate our outlet pressure at the tip. Be careful! P_{01} at the tip, that's what is say 101325 Pa and this is what we are assuming 1200 Pa. So, that's what we will be giving us say our pressure ratio to be 1.011, okay.

$$The\ exit\ Total\ Pressure\ at\ Tip,$$

$$P_{02t} = P_{01t} + \Delta P_t$$

$$\therefore P_{02t} = 101325 + 1200$$

$$\therefore P_{02t} = 102525\ Pa$$

$$And, Pressure\ Ratio$$

$$\pi_{c,t} = \frac{P_{02t}}{P_{01t}}$$

$$= \frac{102525}{101325}$$

$$= 1.0118$$

From our fundamental understanding, we can do our calculation for the temperature rise. So, here if we are putting this number, it says our temperature rise or total temperature rise that's what is coming to be 1.25 K, okay.

$$Temperature\ Rise,$$

$$\Delta T_{0,t} = \left[\left(\frac{P_{01t} + \Delta P_{0,t}}{P_{01t}}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \times \frac{T_{01t}}{\eta_p}$$

$$\therefore \Delta T_{0,t} = \left[\left(\frac{101325 + 1200}{101325}\right)^{\frac{1.4-1}{1.4}} - 1\right] \times \frac{298}{0.8}$$

$$\therefore \Delta T_{0,t} = 1.2551\ K$$

Now, once we know what is our ΔT_0? That's what will be helping us for the calculation of our other parameter, what parameter? We want to calculate, what is whirl component or what will be my blade angle, okay, or what will be my relative blade angle?

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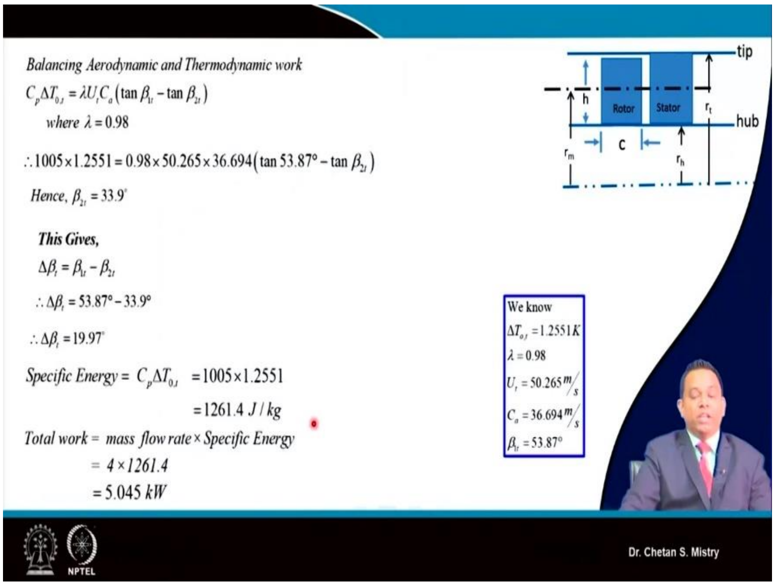

So, here in this case, if you look at we can do balancing between aerodynamic work and thermodynamic work. And if we are doing our calculation, that's what is giving me my β_2 to be 33.9°, okay. So, this is what is giving me 33.9°.

$Balancing\ Aerodynamic\ and\ Thermodynamic\ work,$

$$C_p \Delta T_{0,t} = \lambda U_t C_a (\tan\beta_{1t} - \tan\beta_{2t})$$

$$where, \lambda = 0.98$$

$$\therefore 1005 \times 1.2551 = 0.98 \times 50.265 \times 36.694(\tan 53.87° - \tan\beta_{2h})$$

$$Hence, \beta_{2t} = 33.9°$$

Once, this is what is known to us, we know what is our β_1 at the tip, we know what is our β_2 at the tip. So, we can calculate $\Delta\beta$ at the tip, that's what is coming 19.97°, okay.

$$This\ Gives, \Delta\beta_t = \beta_{1t} - \beta_{2t}$$

$$\therefore \Delta\beta_t = 53.87° - 33.9°$$

$$\Delta\beta_t = 19.97°$$

$$Specific\ Energy = C_p \Delta T_{0,t} = 1005 \times 1.2551$$

$$= 1261.4\ J/kg$$

$$Total\ work = mass\ flow\ rate \times Specific\ Energy$$

$$= 4 \times 1261.4$$

$$= 5.045\ kW$$

And same way we can do our calculation, this is what is for our understanding. Intentionally we have kept this; it says if I am calculating my total power, that's what is coming say 5.045 kW. So, you can understand, we have our design, that's what is tip loaded design, my hub is less loaded, my mid-section is mid loaded and the tip, it is highly loaded, okay. And, that's what is giving my power requirement for that station, that's what is coming to be larger, okay.

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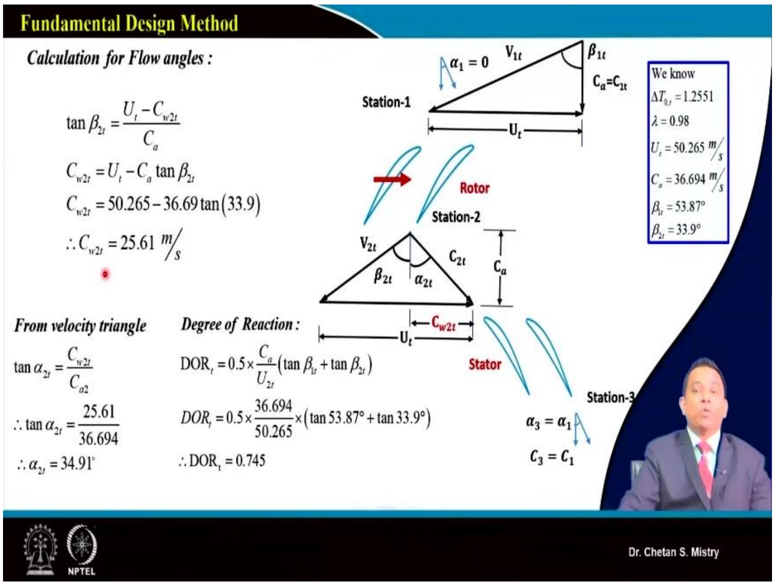

Now, as we have discussed for our hub, we can do our calculation for the tip station and we can calculate what will be our C_{w2}, okay. So, based on our fundamental equation and velocity triangle, we can calculate our C_{w2} at a tip, that's what is coming, 25.61 m/s, okay.

$$\tan\beta_{2,t} = \frac{U_t - C_{w2t}}{C_a}$$

$$\therefore C_{w2t} = U_t - C_a \tan\beta_{2t}$$

$$\therefore C_{w2t} = 50.265 - 36.69\tan(33.9°)$$

$$\therefore C_{w2t} = 25.61\ m/s$$

Now, once this C_{w2}, that's what is known to us, we can calculate what will be our α_2 and this α_2 that's what is coming 34.91°.

$$\tan \alpha_{2t} = \frac{C_{w2t}}{C_{a2}}$$

$$\therefore \tan \alpha_{2t} = \frac{25.61}{36.694}$$

$$\therefore \alpha_{2h} = 34.91°$$

Now once this is what is known to us, we can do our calculation for degree of reaction, because my β_1 at the tip is known my β_2 at the tip is known, my C_a and U_t they are known to be. So, we can do our calculation for degree of reaction and that's what is coming 0.74, okay.

$$Degree\ of\ Reaction,$$

$$DOR_t = 0.5 \times \frac{C_a}{U_{2t}} (\tan \beta_{1t} + \tan \beta_{2t})$$

$$\therefore DOR_t = 0.5 \times \frac{36.694}{50.265} \times (\tan 53.87° + \tan 33.9°)$$

$$\therefore DOR_t = 0.745$$

So, we can say now this is also coming in a reasonable range, okay. And, you know, reasonable in the sense at the tip, we will never be having this degree of reaction to becoming negative or 0. So, that is okay, okay!

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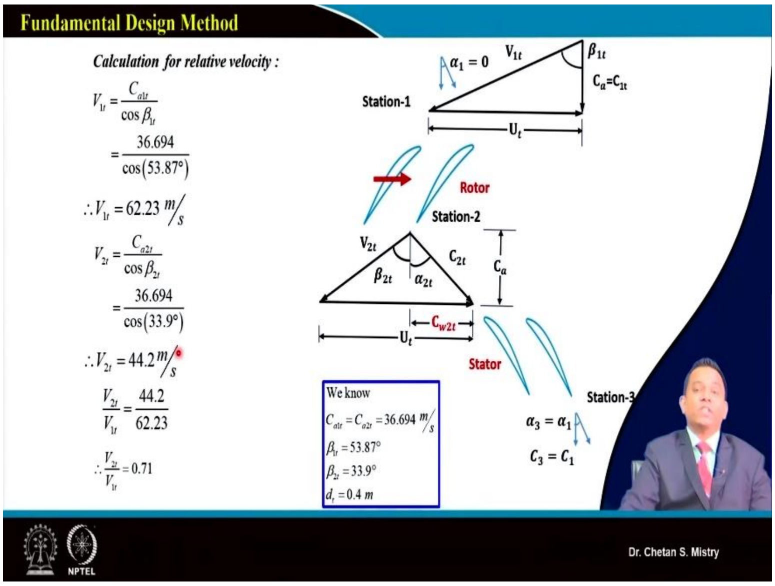

Now, we will be checking with what is happening with our relative velocity ratio. So, based on our velocity triangle at the entry and velocity triangle at the exit of our rotor, we can do our cos correlation; it says my V_1, that's what is coming to be 62.23 m/s. And same way at the exit, we can calculate our relative velocity, that's what is coming 44.2 m/s. And, it says my relative velocity ratio, that's what is coming 0.71. So, this is also in the range of what we can say 0.72. So, we are not bothering at this moment in sense of this number also, okay.

$$Calculation\ for\ relative\ velocity,$$

$$V_{1t} = \frac{C_{a1t}}{\cos\beta_{1t}}$$

$$= \frac{36.694}{\cos(53.87°)}$$

$$\therefore V_{1t} = 62.23\ m/s$$

$$V_{2t} = \frac{C_{a2t}}{\cos\beta_{2t}}$$

$$= \frac{36.694}{\cos(33.9°)}$$

$$\therefore V_{2t} = 44.2\ m/s$$

$$\frac{V_{2t}}{V_{1t}} = \frac{44.2}{62.23}$$

$$\therefore \frac{V_{2t}}{V_{1t}} = 0.71$$

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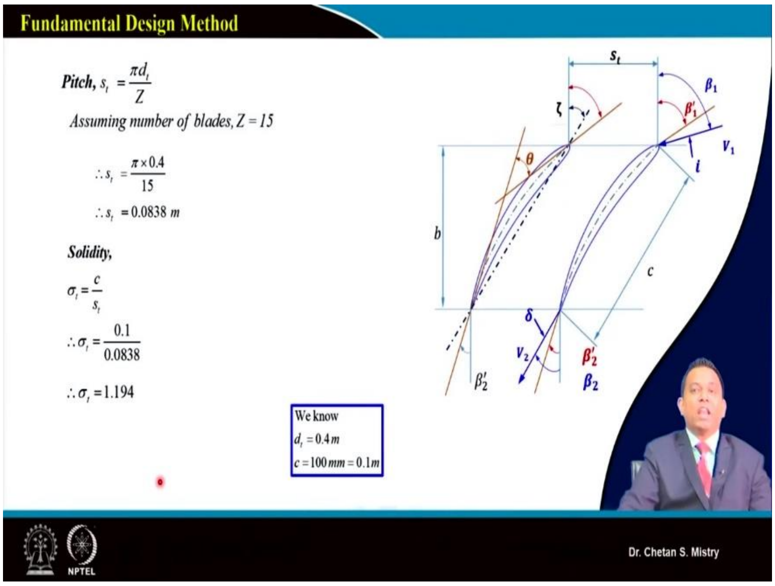

Now, we have done all this calculation. Next parameter we need to check, that's what is with the diffusion factor. So, for diffusion factor calculation, as we have discussed earlier, we are looking for the calculation of the solidity. Be careful here, when we are calculating our pitch, we need to consider our tip diameter and number of blades, that's what is say 15. If you are putting that number, it says my pitch, that's what is coming 0.0838 meter.

You can understand, my pitch at the tip that's what is coming to be larger, my pitch at the hub that's what is coming to be lower, because that's what it is a function of my radius, okay. My chord that's what we have assumed to be constant. So, we can say solidity, that's what is coming as 1.19 at the tip station.

$$Pitch, s_t = \frac{\pi d_t}{Z}$$

$$Assuming\ number\ of\ blades, Z = 15$$

$$\therefore s_t = \frac{\pi \times 0.4}{15}$$

$$\therefore s_t = 0.0838\ m$$

$$Solidity\ of\ rotor\ at\ hub\ station,$$

$$\sigma_t = \frac{c}{s_t}$$

$$\therefore \sigma_t = \frac{0.1}{0.0838}$$

$$\therefore \sigma_t = 1.194$$

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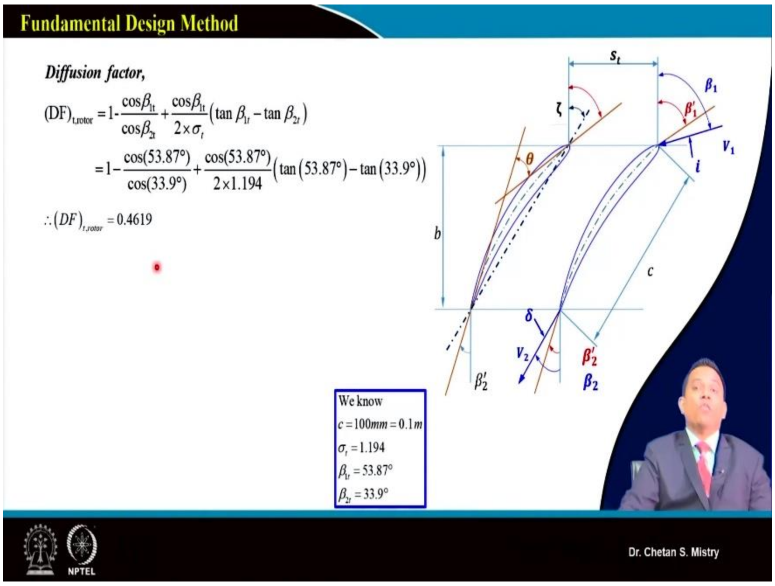

Now, once this is what is known to us, we can do our calculation for the diffusion factor for rotor at the tip station and that's what is coming 0.4619. So, we can say this is also coming in a reasonable range, 0.46 it is okay.

$$Diffusion\ factor,$$

$$(DF)_{t,rotor} = 1 - \frac{\cos\beta_{1t}}{\cos\beta_{2t}} + \frac{\cos\beta_{1t}}{2\times\sigma_t}(\tan\beta_{1t} - \tan\beta_{2t})$$

$$= 1 - \frac{\cos(53.87°)}{\cos(33.9°)} + \frac{\cos(53.87°)}{2\times1.194}(\tan(53.87°) - \tan(33.9°))$$

$$\therefore (DF)_{h,rotor} = 0.4619$$

So, we have done our calculation at hub station, we have done our calculation at a tip station and we have verified our required parameter in sense of degree of reaction, relative velocity ratio and diffusion factor. And, we have calculated all our flow angles as well as our same velocity component.

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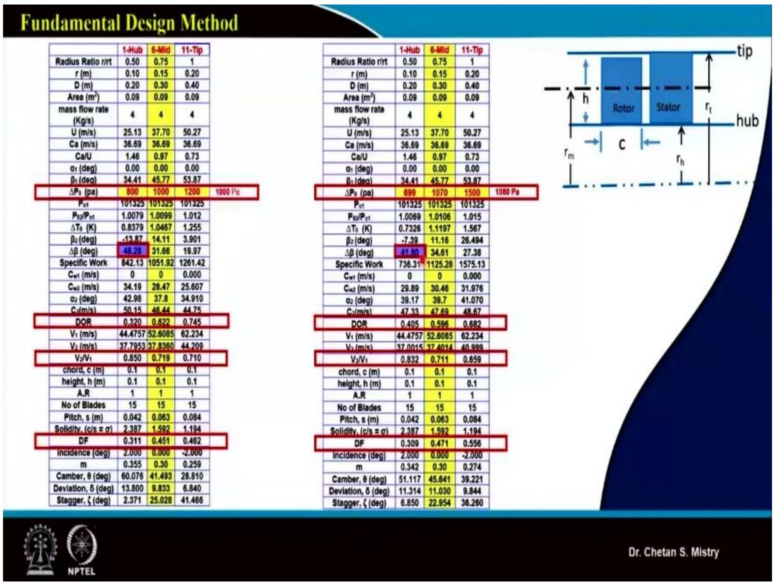

Now, let us come to what all we have done. So, as we have discussed for our fundamental understanding, again, when we are using this fundamental method for that also it is preferred, we will be doing our calculation using excel sheet program, okay. So, this is what is my mid station calculation, okay. So, that's what will be remaining same, okay. That's what we have done our calculation for, say our free vortex design, same logic that's what is applicable here, there is nothing different in sense of say, these numbers, okay.

Here in this case, where the change, that's what is coming, that's what is coming here. Now, all our calculation, that's what is based on ΔP_0. So, here for hub, we have assumed to be 800 Pa and for the tip, we have assumed that to be 1200 Pa and if you recall, when we have done our calculation for free vortex, at mid station we have done calculation for C_{w2} into R_2 at mid station that's what was giving some constant and from that we have done our calculation for say our tangential velocity component or whirl component. Here in this case, we are doing our calculation based on ΔP_0.

So, here if you look at, based on this ΔP_0 we are doing our calculation for C_{w2}, we are doing our calculation for β_2 and all those numbers, okay. So, this is what is the difference. And, that is the reason why intentionally we have done our calculation at the hub station and at the tip station. So that, you will get clarity how exactly these numbers are coming. There is nothing magic in doing this calculation, okay. So, be careful! You just make your excel sheet program that's what we will be ready for this fundamental method also, okay. Now here in this case, if you look at, this is what is giving me my 1000 Pa.

So, you know, if you are taking your average, that's what is giving me 1000 Pa; this is what is my requirement, okay. Now here, if you look at my $\Delta\beta$, that's what is coming 48.28; you can say, this number is coming slightly on the higher side, we are looking for our $\Delta\beta$ to be in the range of 45. And this is what is coming slightly on higher side. So, you know, you can understand, we need to do something for changing this number. Let us see what to do with. Here, if you look at, this is what is giving me idea about the degree of reaction, we have no issue with degree of reaction at the hub, that's what is coming to be positive. So, it is okay. We are considering our say relative velocity ratio, that's what is say it is changing from 0.85 to 0.71.

So, this 0.71 that's what we will say, okay; we need to do something there in order to modify this number, okay. Now, next, that's what is coming in sense of my diffusion factor. So, here if you look at my diffusion factor, that's what is coming 0.31 at my hub and 0.46 at tip. Now, as I told, we have so much of flexibility by using this axial sheet program. Suppose say, you want to modify your diffusion factor, what change you will be doing? You will be changing your number of blades, okay. Just change that number of blades, that's what will be changing all your calculation for diffusion factor, that's what we will be giving the change in your camber angle and all those parameters because your pitch, that's what is changing, okay.

So, your camber angle will be changing, your deviation angle will be changing, your stagger angle will be changing, they all are interrelated parameters. So, that's what is the flexibility. So, you can say here, I can play with changing the number of blades. You say I need to go with say some higher loading, I am looking for a higher tip loading compared to 0.46, I want to go with 0.5. Yes, you can play with these numbers, you can change your say chord, you can change your number of blades, okay.

So, that's what is a flexibility what we are getting when you are using this excel sheet program. So, that is the reason why I insist all the time because when you are writing your code, for writing of code all the time, we will be having say different kind of feeling, okay. And, may not be calculating say we will not be having the feeling of how my angles, how my parameter, that's what is changing at the hub, how my parameter that's what is changing at say tip. So, this is what is you know, we will give you a feeling of exact view of how would a variation that's what is happening, okay.

Now, let me discuss something different. Here, in this case as we have discussed, we are having our $\Delta\beta$, that's what is coming to be large, okay. So, in order to address this kind of issue, just look at here, this ΔP_0 that's what we have modified. Now, let me put one point here. Now, what we are expecting is our pressure rise what we are expecting, that's what is 1000 Pa. These all designs what we are doing, we are not knowing what kind of loss that's what will be happening. This loss majorly is because of the tip clearance, what we are having are we going in sense of 1 mm, 2 mm or 3 min clearance or be in sense of percentage of height.

So, you know, we need to take care at the initial stage only. So, that later it will not create the trouble for us. So, in spite of say having 1000 Pa, let me consider slightly on the higher number there is nothing wrong in doing this thing. Even for a free vortex, at mid station you can take that number, there is nothing wrong in that, because we are not having idea what will be the losses and how much pressure loss that will be happening because of my tip clearance because here we are not having any consideration for the tip clearance, okay.

So, what we have done, here in this case, you can say at hub we are having our say ΔP_0 is 699, at mid station also we have changed, that's what is the flexibility; that's what I was telling you. Say here, in this case, you play with this number, and just check with what all changes, that's what is happening, okay. So, here at mid-station, we have considered that to be say 1070. And, you can say at the tip, we have considered that to be 1500 Pa, okay. Now, what will happen because of that, just look at this $\Delta\beta$ here, for our earlier loading case, it was coming 48.28, that's what we have reduced to 41.80, okay. Where it is reflecting? You can say, that's what is reflecting with our degree of reaction.

So, you can say my degree of reaction, that's what has increased near the hub region. Now, what is happening at the tip region? It says my degree of reaction, that's what is decreased by say 0.682, earlier it was say 0.74, okay. Now, when we are comparing our relative velocity, it says my relative velocity I have moderately compiled here at the hub, but near the tip region, that's what is coming to me slightly on the lower side, we prefer to have 0.72 but this is what is coming around 0.66. It is designer's choice, you can, you can play with the numbers. Here, you can modify that part. And, if we compare our diffusion factor, just look at, at the hub, we are having our diffusion factor to be 0.30 and at the tip, we are having diffusion factor to be 0.55.

So, we can say, we have increased our diffusion factor near the tip region by changing our loading, okay. So, accordingly if you compare your angles, it clearly gives, we are able to maintain our camber angle within certain range. Because my blades twist what we say in sense of $\Delta\beta$, that's what is very important, okay. And if you recall, for free vortex design, we have realized our $\Delta\beta$, that's what is coming to be say higher near the hub region. And, we have no control for that, it is by default it will come because my diameter is smaller, and maybe my rotational speed that's what is smaller.

So, my U will be smaller. Now, here in this case, when we are opting for this design concept, that's what is in our own hand, we can control in sense of degree of reaction, we can control what blade turning angle we are looking for. And, that is the reason why this is what is one of the fundamental I say this is, what is say fundamental method and that's what is most preferred. Most of the design what all we have done up till now, that's what is based on our fundamental approach and there is nothing wrong; all what stages we have designed, what all rotors we have designed using this concept they are safely running without any problem, okay.

So, we can realize now, this is also one of the approach for the design. So, later part in sense of how we will be dividing, that's what is very important, that's what we will be discussing in the next session. But you just realize one thing, say when we are comparing our design aspect for free vortex and the fundamental method, we are having more flexibility when we are approaching or when we are using our fundamental design approach, okay.

And, we must realize what are the benefits of using this excel sheet program and we will soon be realized and we will be getting matured with using this excel sheets only. As and when we will be doing our design, we will be having excel sheet program with us, okay.

So, now in next lecture, we will be discussing here we have discussed about what will be my ΔP_0 at hub, what will be my ΔP_0 at the tip. Now, at 11 stations we need to distribute that ΔP_0 in a systematic way then only we will be getting our smooth curve for the blade otherwise it will be creating trouble, okay.

Then we will be discussing how do we do our design for the stator and we will be finalizing the stage design. Then we will try to understand what all changes we are bringing by incorporating free vortex method as well as this fundamental method. Thank you. Thank you very much! I do prefer you just go with doing the excel sheet program. And, at the same time, you just try to make the code for making of blades. Thank you. Thank you once again.