Aerodynamic Design of Axial Flow Compressors & Fans
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Lecture 38
Design Low Speed Compressor (Contd.)

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Hello, and welcome to lecture 38. We started discussing about Design of Low Speed Axial Low Compressor. So, in last lecture, we started discussing about say, transformation or use of low speed facility in order to test high speed compressors. And, we have discussed some of the important aspects, that's what needs to be considered. So, today as we have discussed in last lecture, we will be starting with the data, that's what is given to us.

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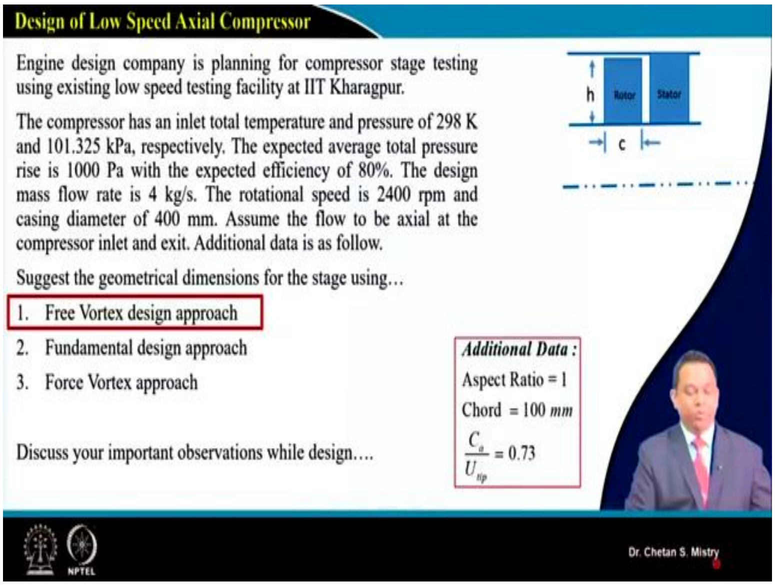

Now, here in this case, say…we will be starting with say…our initial case. So, we will be discussing today how to start doing the design using the free vortex concept. So, let us move with.

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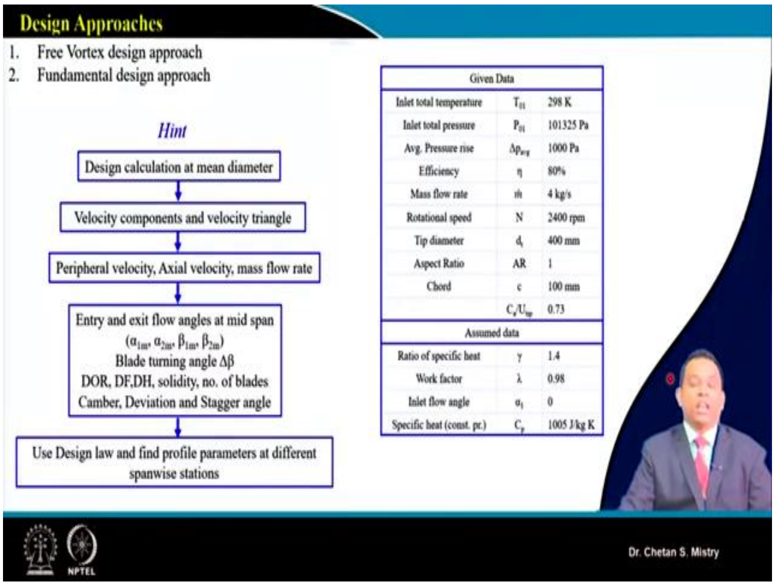

So, we are asked to do design for say free vortex concept or using free vortex concept. Second, that's what is by using our fundamental method, and third, that's what is by using forced vortex method. Now, for all this method, as we have discussed during our classes, very first thing, that's what we need to do is we need to do our calculation at the mid station. So, here this is what is a hint, it says we need to do our calculation at the mid station.

Suppose for present case, we are doing our calculation at 50% span because this compressor is say low speed compressor. So, at mid station, we need to decide with what is our mean diameter, we need to do our calculation for different velocity components and different velocity flow angles, we need to use our fundamentals of velocity triangle, we are looking for peripheral speed, we are looking for axial speed, mass flow rate, all these parameters, that's what is coming into the picture.

Based on that we need to calculate different entry and exit flow angles, absolute flow angles, we need to check with what is our degree of reaction, diffusion factor, De Haller factor. We need to calculate different angles called say camber angle, deviation angle, stagger angle, and based on that we will be making our framework, initial framework. Then, what design method we are adopting or what design approach we will be adopting that's what we will be modifying my calculation at different stations.

So, fundamental part for all the three design discussion, that's what will remain same, our initial calculation that's what is happening at the mid station or mean section. Now what all data, that's what is available with us is my entry temperature, entry pressure, what pressure rise we are expecting, our efficiency that's what is given 80%, say mass flow rate is 4 kg/s, rotational speed is 2400 rpm, tip diameter is 400 mm, aspect ratio given is 1 and chord is given say 100 mm and one more parameter that's what is flow coefficient based on say tip peripheral speed is 0.73.

Let us assume some data, say we will be having $\gamma = 1.4$. My work done factor, that's what we are assuming to be 0.98, my entry flow angle and exit law angle it says 0° and specific heat at constant pressure, that's what we are taking 1.005 $kJ/kg\ K$, okay.

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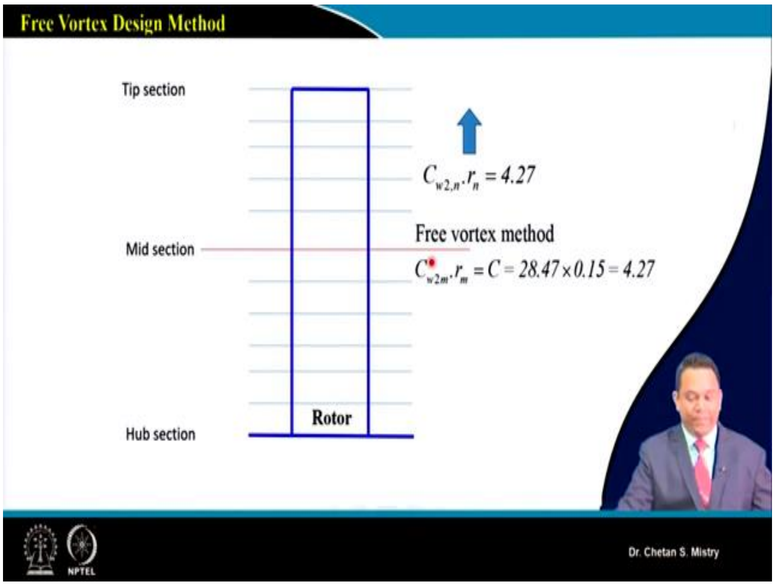

Now let us start with, so our fundamental, that's what will be remained here. It says suppose this is what is my rotor, at the mid-section I will be calculating my C_w that's what is my whirl component at the exit. If my mean diameter or the radius is known to me, I can calculate my $C_w \cdot r = Constant$, that's what will remains constant throughout my span. Here in this case, it is given my entry flow angle, that's what is 0. I have axial entry that means my whirl component at the entry C_{w1} that's what is equal to 0.

Now once we calculate this constant, we need to apply this constant in $C_w \cdot r$, that's what is equal to that number, and that's what we will be applying at different radius, that's what will be giving us what will be my whirl distribution at different stations. Now, once we are calculating our whirl component, we are able to calculate our blade angles, we are able to calculate our flow angles, we are able to calculate all parameters which we are looking for at different station.

So, at this moment, let us see, suppose say this rotor I will be dividing into 11 stations, okay. And this is what is my mid station, that's what is at say 50% of my span, okay.

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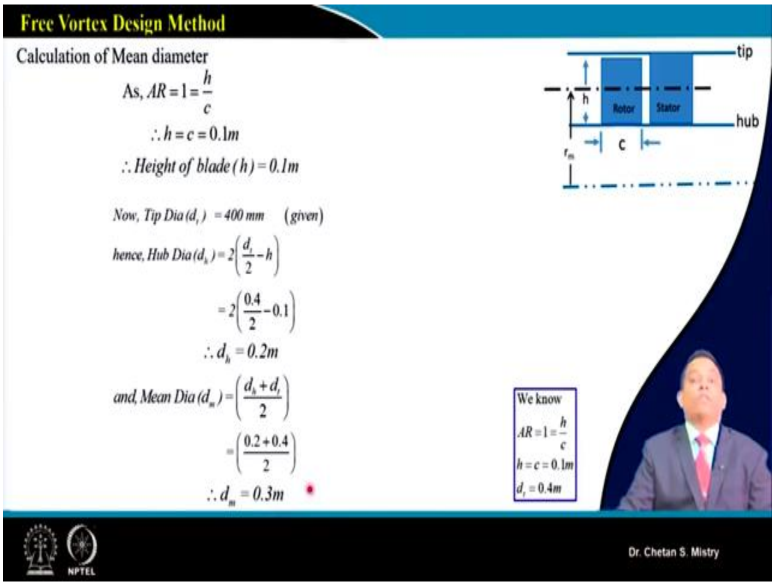

Now, let us start with. So, very first thing, that's what is we need to calculate what is our mean diameter. So, what all we know, we are given with the aspect ratio. So, here if you look at, this is what is say, I can say, this is what is my rotor and this is what is my stator, that's what is having aspect ratio is 1, that means my height of the blade to chord ratio, that's what is say 1, okay.

So, I can say my height, that's what is equal to 0.1 m. Now, we have given our tip diameter, that's what is say 400 mm. So, if my tip diameter, that's what is known to me, and if I know what is the height of my blade, we can calculate what will be my hub diameter and what will be my mean diameter.

$$Calculation\ of\ Mean\ diameter,$$

$$As, AR = 1 = \frac{h}{c}$$

$$\therefore h = c = 0.1\ m$$

$$\therefore Height\ of\ blade\ (h) = 0.1\ m$$

So, here in this case, if we consider, say my hub diameter, that's what we can write down. This is what is equal to 2 times dh by 2 minus height of my blade. If we are calculating that, it says my hub diameter, that's what is coming 0.2 m.

$$Now, Tip\ dia\ (d_t) = 400\ mm\ (given)$$

$$Hence, Hub\ Dia\ (d_h) = 2\left(\frac{d_t}{2} - h\right)$$

$$= 2\left(\frac{0.4}{2} - 0.1\right)$$

$$\therefore d_h = 0.2\ m$$

We can calculate what will be my mean diameter. It is nothing but my average, $\left(\frac{d_t+d_h}{2}\right)$. That's what is giving me my mean diameter to be 0.3. So, this is what is a location, where we will be doing all our calculation for the initial stage.

$$and, Mean\ Dia\ (d_m) = \left(\frac{d_h + d_t}{2}\right)$$

$$= \left(\frac{0.4 + 0.4}{2}\right)$$

$$\therefore d_m = 0.3\ m$$

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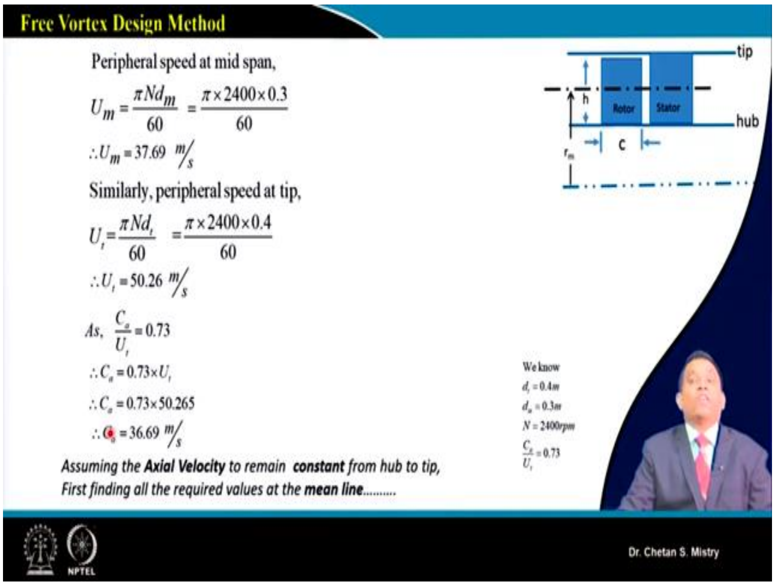

Now, once we know what is our mean diameter, we can calculate the peripheral speed at the mid station. So, my peripheral speed at mid span, we can say, it is $\frac{\pi N d_m}{60}$. Since my rotational speed is given, that is 2400 rpm, my mean diameter we have calculated 0.3, that's what is giving say peripheral speed at the mid span as 37.69 m/s, okay.

$$Peripheral\ speed\ at\ mid\ span,$$

$$U_m = \frac{\pi N d_m}{60} = \frac{\pi \times 2400 \times 0.3}{60}$$

$$\therefore U_m = 37.69\ m/s$$

Similarly, we can do our calculation at the tip station, because my casing diameter is also known to me. So, we can write down, it is $\frac{\pi N d_t}{60}$, my tip diameter given, it is 0.4, okay. So, that's what is giving my tip peripheral speed as 50.26 m/s.

$$Similarly, Peripheral\ speed\ at\ tip,$$

$$U_t = \frac{\pi N d_t}{60} = \frac{\pi \times 2400 \times 0.4}{60}$$

$$\therefore U_m = 50.26\ m/s$$

Now, very important parameter for us is to calculate the axial velocity, since we are given with C_a/U_{tip}, that's what is 0.73. So, based on that, we can calculate what will be our axial velocity. So, it says my axial velocity it is coming 36.69 m/s.

$$As, \frac{C_a}{U_t} = 0.73$$

$$\therefore C_a = 0.73 \times U_t$$

$$\therefore C_a = 0.73 \times 50.265$$

$$\therefore C_a = 36.69\ m/s$$

Now, this axial velocity, that's what we are assuming constant throughout my stage, okay. So, this is what will be helpful for us to go with say next step calculation. So now, we know what is our axial velocity, we know what is our peripheral velocity or peripheral speed.

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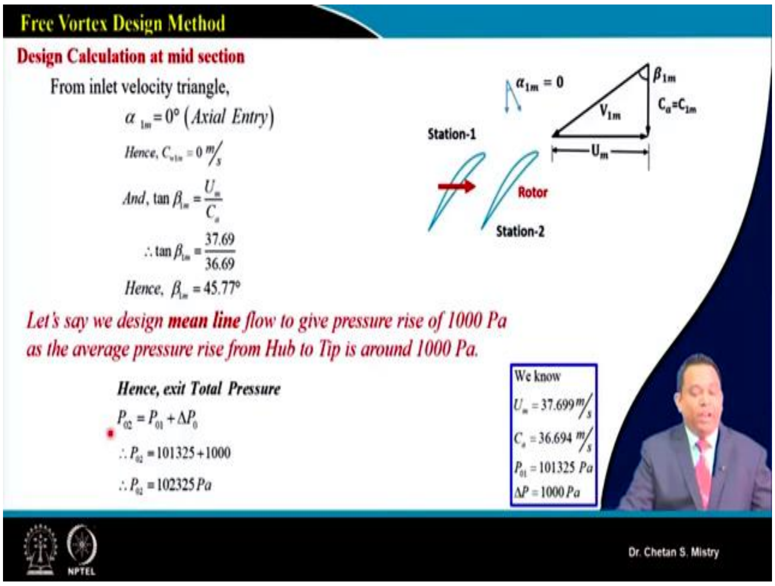

So, next thing, that's what is to calculate what will be my flow angles, okay. So, if you are looking for the flow angle, say…it says, I am having axial entry so my α_1 at mid station, that's what is equal to 0 ($\alpha_{1m} = 0$). And based on this velocity triangle, we can calculate what will be my β_1, okay, that's what is say my relative flow angle. So, that's what we can write down my $\tan\beta_{1m} = \frac{U_m}{C_a}$. Since my peripheral speed at mid station is known, and axial velocity is known, that's what will be giving me my β_1, it is coming 45.77°.

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

$$\alpha_{1m} = 0°\ (Axial\ Entry)$$

$$Hence, C_{w1m} = 0\ m/s$$

$$And, \tan\beta_{1m} = \frac{U_m}{C_a}$$

$$\therefore \tan\beta_{1m} = \frac{37.69}{36.69}$$

$$Hence, \beta_{1m} = 45.77°$$

Now, no other parameter that's what is known to us at this moment, for the further calculation. So, what we will be doing? Say, we will be taking, it says I am expecting pressure rise of 1000 Pa through this stage, okay. Under that configuration what we will be doing? Say, at the mid station, we will be taking this say 1000 Pa pressure. So, it says, at exit my total pressure I can calculate. It is, $P_{01} + \Delta P_0$, that is nothing but $101325 + 1000$ that's what will be giving me 102.32 kPa. So, now, I have my total pressure at the outlet, I have my total pressure at the inlet.

$$Hence, exit\ Total\ Pressure$$

$$P_{02} = P_{01} + \Delta P_0$$

$$\therefore P_{02} = 101325 + 1000$$

$$\therefore P_{02} = 102325\ Pa$$

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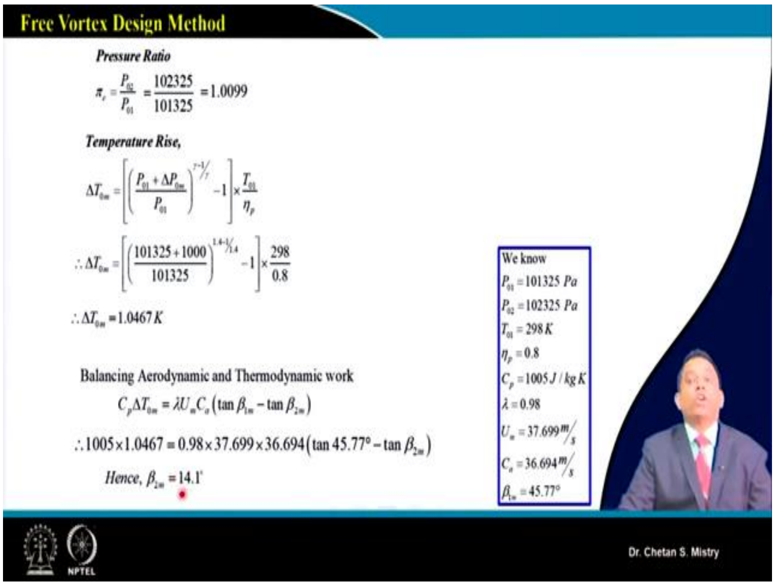

Once, we know this pressure at inlet and outlet, we can calculate what will be my pressure ratio. So, it says if you are taking P_{02}/P_{01} it is coming 1.0099, okay.

$$Pressure\ Ratio$$

$$\pi_c = \frac{P_{02}}{P_{01}} = \frac{102325}{101325} = 1.0099$$

Now, since we know what is our pressure ratio, we can calculate what will be my temperature rise, total temperature rise.

So, we know from our fundamental, we can say, my P_{02}/P_{01}, that's what we are writing as say

$$Temperature\ Rise,$$

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

Now, for this case, my entry temperature it is given, it is 298. Our efficiency also is given, it is 80%. So, we can calculate what will be my total pressure rise in a stage at mid station, that's what is coming 1.0467 K.

$$\Delta T_{0m} = \left[\left(\frac{101325 + 1000}{101325}\right)^{\frac{1.4-1}{1.4}} - 1\right] \times \frac{298}{0.8}$$

$$\Delta T_{0m} = 1.0467\ K$$

Now, this is what will be very helpful to us for moving further. Now, be careful, when we are not having any data, just dig in the details what is available, if not then maybe you need to go with certain assumptions. So, that is also one of the possibility. If you recall, when we were discussing how to decide with say per stage pressure rise, for initial stage, for say middle stage and for rear stages, there along with pressure ratio and efficiency, we were given with ΔT_0 range also. So, that is also one of the startup for our calculation, okay. So, keep that also in mind, okay.

Now here, what we know? We can compare our aerodynamic work and thermodynamic work at mid-station. So, we can write down $C_p \Delta T_{0m}$ that's what is say my $\lambda U_m C_a(\tan\beta_{1m} - \tan\beta_{2m})$. Here, in this case, my ΔT_0 is known to me, my work done factor is known, peripheral speed and mid station is known, axial velocity is known and β_1 we have calculated. So, that's what will be giving me what will be my relative blade angle or relative flow angle at the outlet of my rooter. So, this is what is coming say 14.1°.

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

$$C_p \Delta T_{0m} = \lambda U_m C_a(\tan\beta_{1m} - \tan\beta_{2m})$$

$$\therefore 1005 \times 1.0467 = 0.98 \times 37.699 \times 36.694(\tan 45.77° - \tan\beta_{2m})$$

$$Hence, \beta_{2m} = 14.1°$$

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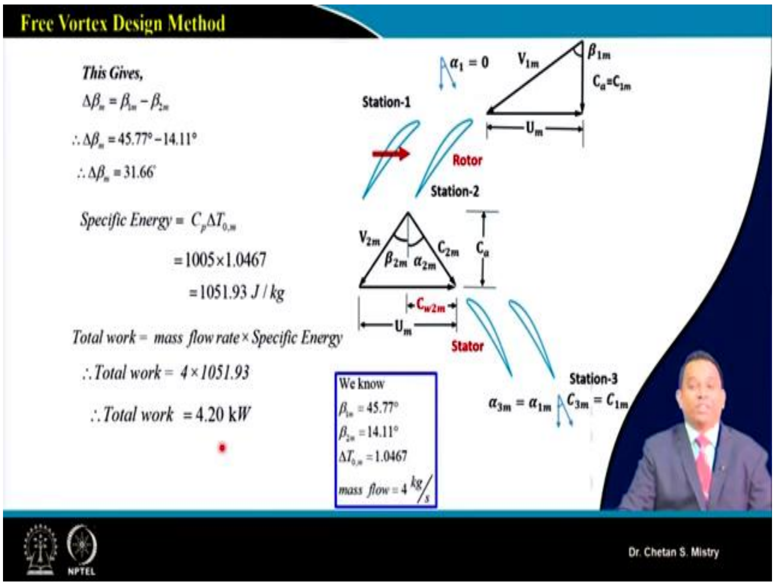

Now, we can say, we have data that's what is available, we know what is our β_1, what is our β_2. So, once we know what is β_1 and β_2, we can calculate what will be my blade deflection angle or we can say what will be my $\Delta\beta$. So, it says my $\Delta\beta_m$, that's what is coming 31.66°, okay.

$$This\ gives,$$

$$\Delta\beta_m = \beta_{1m} - \beta_{2m}$$

$$\therefore \Delta\beta_m = 45.77° - 14.11°$$

$$\therefore \Delta\beta_m = 31.66°$$

Now, we want to calculate what will be say total amount of work, that's what is required or what need to be the power supply for this kind of compressor.

So, in order to do that calculation, we can calculate what is our specific energy, you can say, that's what is $C_p\Delta T_0$. Since, this numbers are known to us, we can say, that's what is coming 1051.93 J/kg.

$$Specific\ energy = C_p \Delta T_{0,m}$$

$$= 1005 \times 1.0467$$

$$= 1051.93\ J/kg$$

Now, we are looking for what will be our power consumption, we can write down that's nothing but mass flow rate into specific energy. If we are putting that number it says my total work required or power input required to run this compressor, it is coming 4.20 kW.

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

$$\therefore Total\ work = 4 \times 1051.93$$

$$\therefore Total\ work = 4.20\ kW$$

This is what is very important when we are deciding, say…making these experimental facilities. So, this is what we will be giving like roughly what needs to be my specification for the motor, okay.

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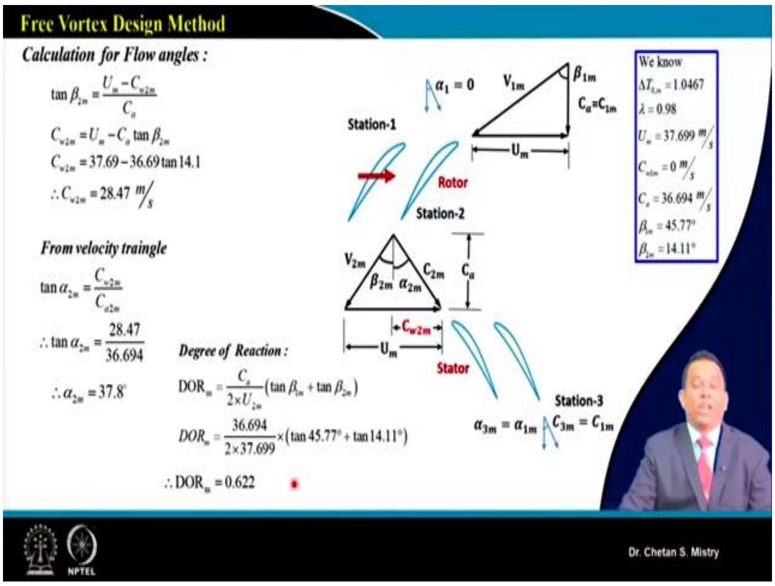

Now, once we have calculated what all we know about $\beta_1, \beta_2, \alpha_1$, we will be doing our further calculation for other angles velocity components. Because that's what is important for calculation of our parameters called say diffusion factor, degree of reaction. For all other flow angle calculation, these are the fundamental requirements. So, we can say, if we are looking at this outlet velocity triangle for the rotor, we can say, my tan β_{2m}, that's what is given by $\frac{U - C_{w2}}{C_a}$, okay. Now, that's what will be giving me what will be my say tangential speed or what will be my swirl velocity. So, my swirl velocity, that's what is coming as say 28.47 m/s.

$$Calculation\ for\ flow\ angles,$$

$$\tan\beta_{2m} = \frac{U_m - C_{w2m}}{C_a}$$

$$C_{w2m} = U_m - C_a \tan\beta_{2m}$$

$$C_{w2m} = 37.69 - 36.69 \tan 14.11$$

$$\therefore C_{w2m} = 28.47\ m/s$$

This is what is very important for us, because we are discussing at this moment design using free vortex concept; where we are looking for our tangential velocity component or whirl velocity component into radius, that's what will be coming to be constant. So, this is what we are looking for, okay.

Now, based on this velocity triangle, we can calculate what will be our α_2. This tan α_2, we can write down, that is C_{w2}/C_a. And that's what is coming 37.8°. Do not get confused in sense of C_{a1}, C_{a2}, we have assumed our axial velocity to be constant, okay.

$$From\ Velocity\ triangle,$$

$$\tan\alpha_{2m} = \frac{C_{w2m}}{C_{a2m}}$$

$$\therefore \tan\alpha_{2m} = \frac{28.47}{36.694}$$

$$\therefore \alpha_{2m} = 37.8°$$

Now, all these numbers they are known to us, at mid-station, we can calculate our degree of reaction. Because my degree of reaction, that's what is given by $\frac{C_a}{2\times U_{2m}}(\tan\beta_{1m} + \tan\beta_{2m})$. This blade deflection angle or my blade angles or relative flow angles $\beta_1\ and\ \beta_2$ at mid-station they are known to us, we can put in this equation and that's what is giving me my degree of reaction mid-station to be 0.62. We can say this is what is a reasonable number at this moment, okay.

$$Degree\ of\ Reaction,$$

$$DOR_m = \frac{C_a}{2 \times U_{2m}}(\tan\beta_{1m} + \tan\beta_{2m})$$

$$DOR_m = \frac{36.694}{2 \times 37.699} \times (\tan 45.77° + \tan 14.11°)$$

$$\therefore DOR_m = 0.622$$

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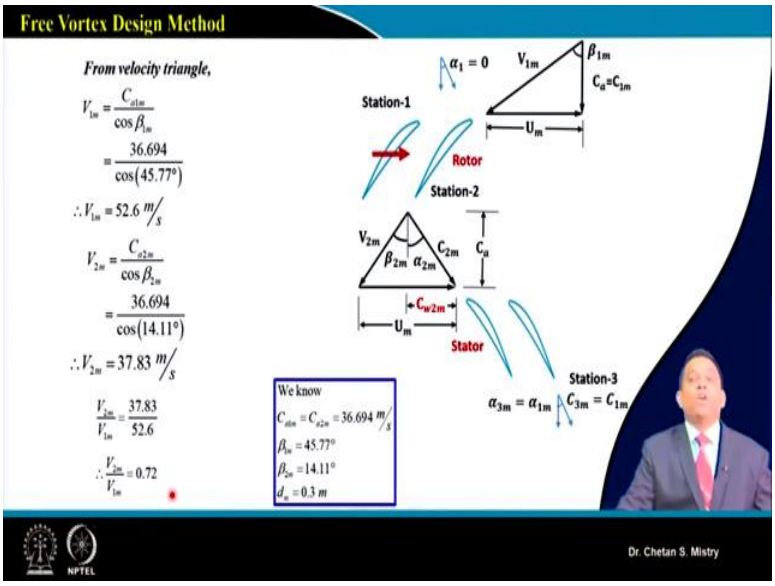

Now, we are also looking for the number, that's what is called De Haller factor or De Haller number. That is nothing but my relative velocity ratio. So, let us calculate this relative velocity component. So, if we are talking about the entry, we can see my V_1, it is given by $\frac{C_a}{\cos \beta_1}$, okay. Since at mid-station, we know what is our $\cos \beta_1$, that's what is giving me my relative velocity at the entry as 52.6 m/s, okay.

$$From\ Velocity\ triangle,$$

$$V_{1m} = \frac{C_{a1m}}{\cos \beta_{1m}}$$

$$= \frac{36.694}{\cos(45.77°)}$$

$$\therefore V_{1m} = 52.6\ m/s$$

Same way, we can do our calculation for relative velocity at the exit, that's what is given by $\frac{C_a}{\cos \beta_2}$. If we are putting that number, it says my relative velocity at the outlet it is coming 37.83. Now physically, we need to understand these numbers, you are clear with what we say, when my relative velocity is coming to the lower at the exit, that's what is representing my diffusion work. So, that's what we are doing here, okay. And it says like if I will be taking the ratio of this relative velocities, that's what is coming 0.72.

$$V_{2m} = \frac{C_{a2m}}{\cos \beta_{2m}}$$

$$= \frac{36.694}{\cos(14.11°)}$$

$$\therefore V_{2m} = 37.83\ m/s$$

$$\frac{V_{2m}}{V_{1m}} = \frac{37.83}{52.6}$$

$$\therefore \frac{V_{2m}}{V_{1m}} = 0.72$$

So, this is what is in a reasonable range at this moment for the mid-station. So, we can say, degree of reaction it is 0.62, this is what is 0.72. Now, our third parameter, as we know, that's what is to check is diffusion factor. Now, in order to do the calculation for the diffusion factor, we are looking for the solidity to be known.

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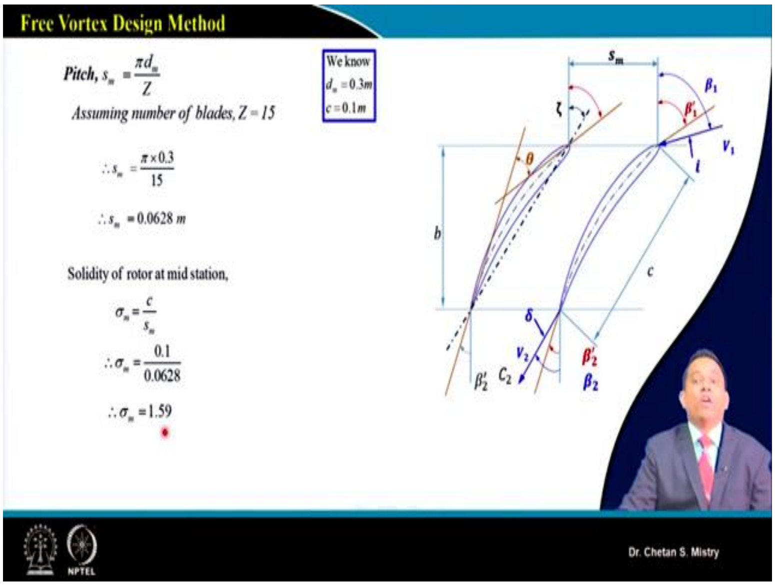

So, let us move there, we can write down, say our pitch, that's what is given by $\frac{\pi d_m}{Z}$, Z is nothing but my number of blades. So, at this moment, let us assume number of blades to be say

15, okay. Now, if you are putting this number of blades to be 15, it says my pitch is coming point 0.0628 m. We will discuss how exactly we are coming with these numbers, but let us assume at this moment say 15, okay. We will be discussing this is what is very important parameter because we know, this is what has direct impact on what all we say in sense of aerodynamic diffusion, okay.

$$Pitch, s_m = \frac{\pi d_m}{Z}$$

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

$$\therefore s_m = \frac{\pi \times 0.3}{15}$$

$$\therefore s_m = 0.0628\ m$$

Now, we know my solidity, that's what we are representing in sense of say chord to pitch ratio and chord it is known to us it is 0.1 m. So, we can write down my solidity it is coming 1.59 at the mid-station, okay.

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

$$\sigma_m = c/s_m$$

$$\therefore \sigma_m = \frac{0.1}{0.0628}$$

$$\therefore \sigma = 1.59$$

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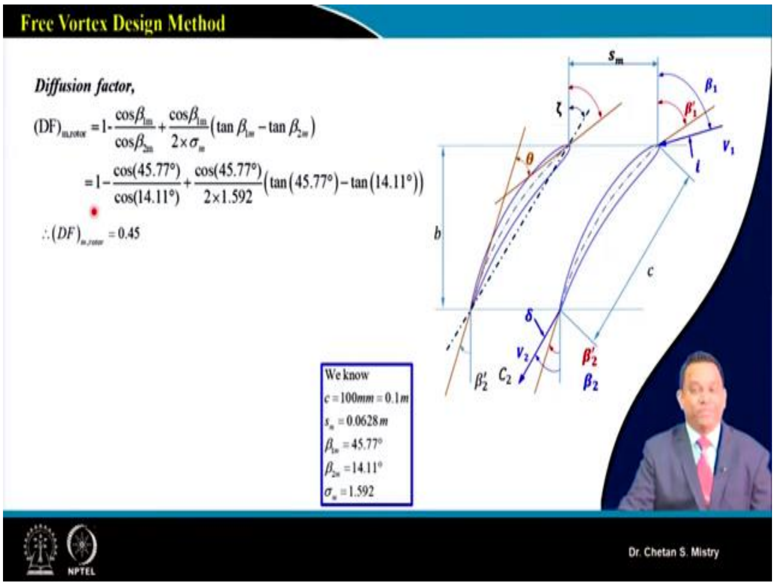

Now, once, this solidity we have calculated, our important aerodynamic parameter Lieblein's factor or we can say diffusion factor, that's what at the mid-station can be calculated by

$$Diffusion\ factor,$$

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

$$= 1 - \frac{\cos(45.77°)}{\cos(14.11°)} + \frac{\cos(45.77°)}{2\times\sigma_m}(\tan(45.77°) - \tan(14.11°))$$

$$\therefore (DF)_{m,rotor} = 0.45$$

So, if we are putting all these numbers, because my $\cos\beta_1$ it is known to us 45.77, say my $\cos\beta_2$ is 14.11 and solidity we have calculated as say 1.592. So, based on that it says my diffusion factor for rotor mid-station, that's what is coming 0.45. So, this is also at this moment a reasonable number.

Now, let me tell you, say what we were discussing in sense of selection of number of blades. Suppose, say this number at mid-station, that's what is coming say lower. You can understand, you will need to play with this solidity. So, maybe you need to change the number of blades because my chord, that's what is given, it is fixed, based on my aspect ratio. So, you can change the number of blades and you can play with in order to set your diffusion factor in the range, okay.

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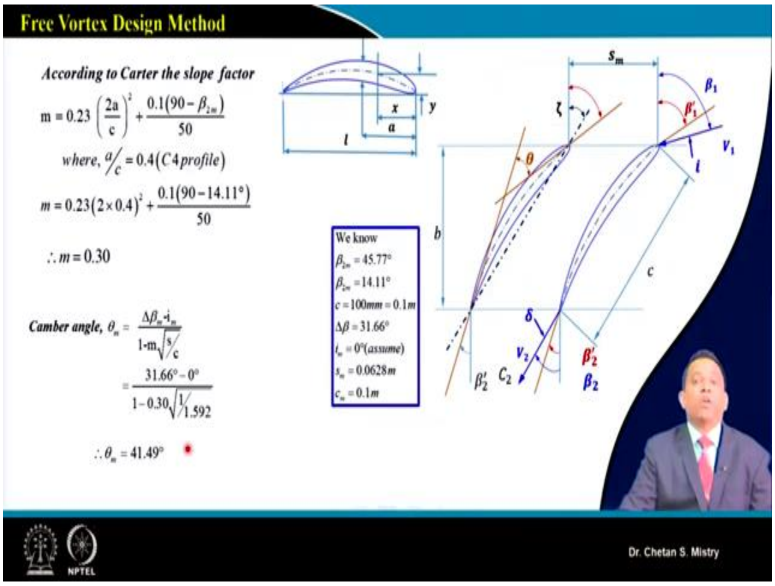

Now, after doing all this calculation, we are more interested in calculating our different flow angles. Suppose if you are looking here, we are looking for what will be my camber angle, what will be my stagger angle, what will be my incidence angle and what will be my deviation angle, okay.

So, if you are considering, say we can use our Carter's rule for the calculation of 'm' factor and as we have discussed for say particular airfoil; suppose, if you are considering C4 airfoil, for that my a by c ratio we have already discussed, a by c that's what is representing the location where I will be having maximum camber.

So, that's what it says that need to be in the range of 0.4. Suppose, if we are considering NACA or NACA profile, for that this will be coming 0.5. So, we will be putting that in order to calculate our 'm' parameter, okay. If you recall, when we are using different kinds of camber line, there also, based on stagger angle calculation we can use this 'm' parameter or based on the 'm' parameter, we can calculate what will be our stagger angle. So, do not forget those plots also, okay.

Now, what we know? My, say camber angle, that's what is given by

$$Camber\ angle, \theta_m = \frac{\Delta\beta_m - i_m}{1 - m\sqrt{\frac{s}{c}}}$$

Now, if we recall, we discussed when we are doing our axial flow compressor, from initially only, we need to provide the incidence angle, okay and as we have discussed, we can safely take the incidence angle variation in the range of plus or minus say minus 2.

So, at this moment for mid-station, we are taking our incidence angle to be 0. Same way, for the tip section we will be assuming say minus 2 and at the hub we can assume safely to be plus 2. So, let me take this incidence angle that to be 0, okay. This is what is our assumption. This $\Delta\beta$, that's what is known to us. So, we can calculate what will be our camber angle, it says this is what is coming 41.49°, okay.

$$\theta_m = \frac{31.66° - 0°}{1 - 0.3\sqrt{\frac{1}{1.592}}}$$

$$\therefore \theta_m = 41.49°$$

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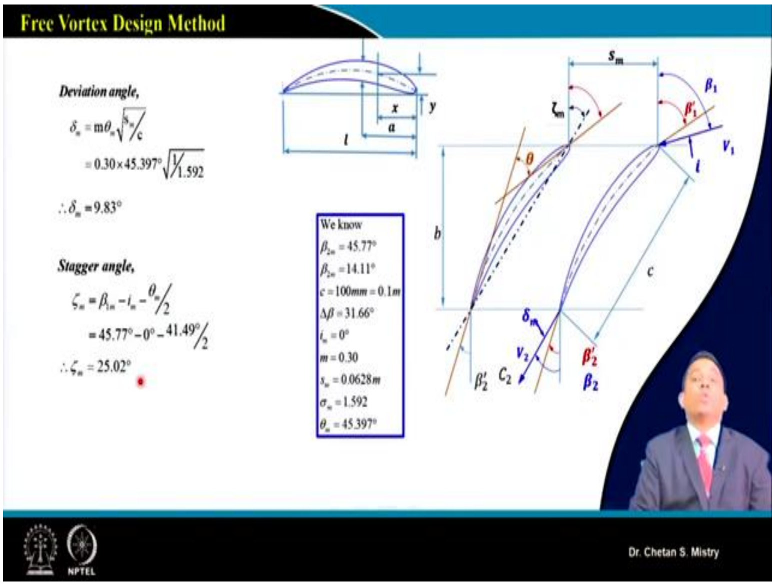

Now, once this number that's what we have known, we can calculate what will be our deviation angle. So, this deviation angle, that's what is correlating my 'm' parameter, what will be my camber angle and what will be my say solidity. So, if we are putting this number, it says my deviation angle, that's what is coming as say 9.83°, okay. So, this is what we have discussed earlier also this is what will give a rough estimation for the deviation angle.

$$Deviation\ angle,$$

$$\delta_m = m\theta_m\sqrt{\frac{s_m}{c}}$$

$$= 0.3 \times 45.397°\sqrt{1/1.592}$$

$$\therefore \delta_m = 9.83°$$

Later on, we will be using or say you will be using or people they are using a computational tool in order to understand what is happening on the suction surface and mainly what is happening needed trailing edge and based on the expectation this deviation angle they are going to change, okay.

Now this is what is say our deviation angle, okay. Next, that's what is a calculation of blade setting angle or our stagger angle. So, this stagger angle, we have discussed that's what is in a function of β_1, incidence angle and $\theta_m/2$. If you are putting all this number, it is coming 25.02°. So, we can say, at mid station, we are able to calculate what all parameters we are looking for.

$$Stagger\ angle,$$

$$\zeta_m = \beta_{1m} - i_m - \theta_m/2$$

$$= 45.77° - 0° - 41.49°/2$$

$$\therefore \zeta_m = 25.02°$$

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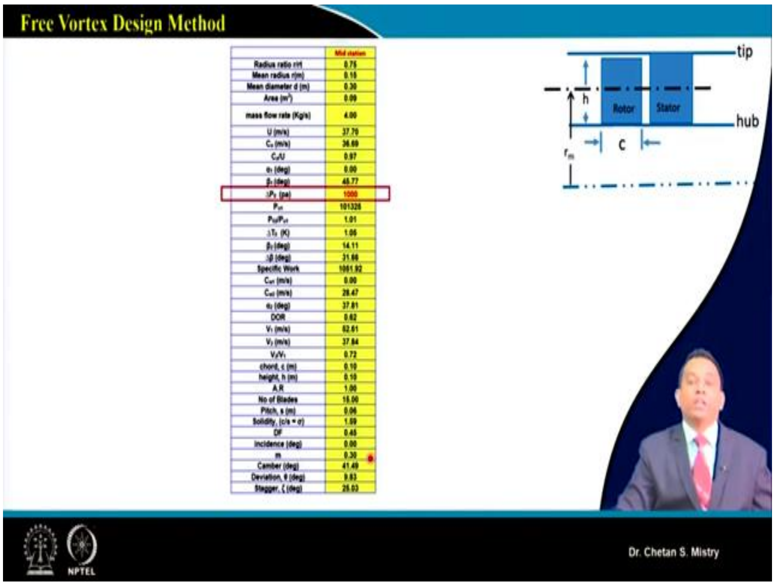

Now, let us see what all we have calculated. So, let me put it here. So, here if you look at, say this is what is say my radius ratio my mean radius, that's what we have taken as 0.15, okay, and my area, that's what is say 0.09 m^2, flow rate, that's what we have taken as a 4 kg/s, peripheral speed at mid-station we have calculated, axial velocity is known, we have calculated our α_1, β_1. We have calculated what will be my β_2, what will be my $\Delta\beta$, specific work done, C_{w1} we have taken that to be 0, C_{w2}, that's what we have calculated based on aerodynamic and thermodynamic work.

We can say, we have calculated our degree of reaction, our relative velocities at the entry and exit, based on that we have calculated the relative velocity ratio then we have calculated our 'm' parameter in order to calculate say diffusion factor, in order to calculate different flow angles.

Now, this is what is advisable to all designers, it is your choice. So, we will be doing our initial calculation using pen and paper. Thereafter we will be using excel sheet. So, we will be calculating our all parameters at the mid-station. So, as we have discussed, we can use our excel sheet, that's what is giving so much of flexibility, you will immediately realize what all will be the use.

So, you have done calculation using pen and paper and those numbers we have calculated that's what we have converted in the formula form or we have made our excel sheet program. So, these all are the parameters which we have calculated with, okay. Now here in this case, my ΔP_0, that's what we have taken to be 1000 Pa.

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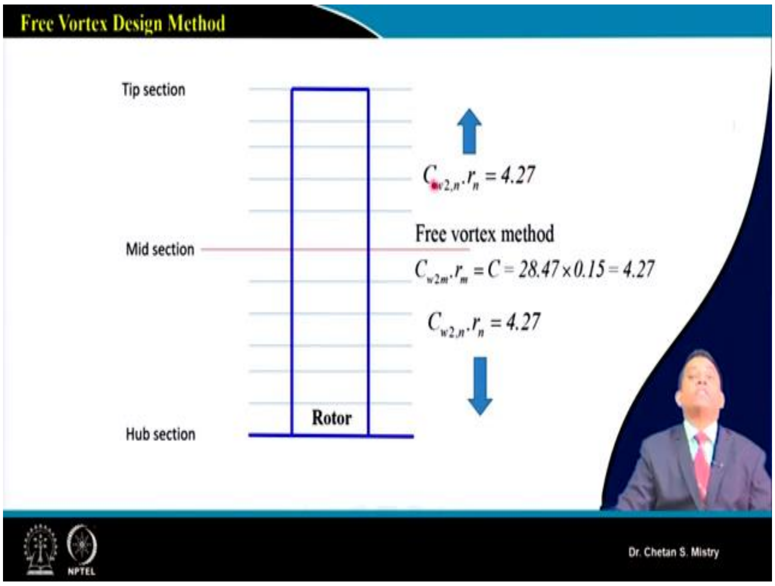

Now, as we have discussed, now our next target, that's what is to calculate the distribution of C_{w2} at different stations, at hub, at mid and at the tip. At mid-station, we have done our calculation, okay. Now, we know what is our hub diameter, we know what is our tip diameter. What we can do? We can divide that into equal number of stages as we discussed. At this moment, we are dividing that into say 11 stations.

So, let us do the calculation what is happening at the hub and what is happening at the tip station, okay. How do we calculate? So here, now my $C_w \cdot r = constant$ that's what is coming 4.27. So, at any station, this radius, that's what is known to me, this constant is known to me, I can calculate what will be my C_w.

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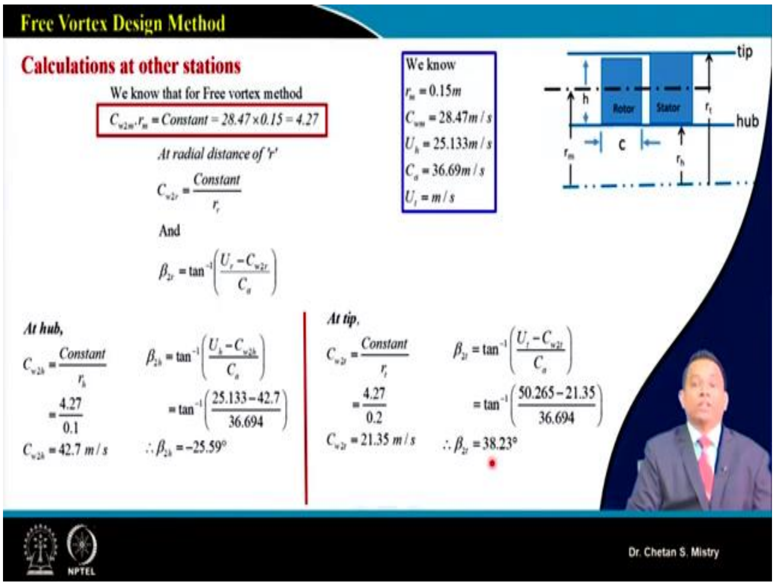

So, let us see. So, we will be putting this as say $C_w \cdot r = constant$, that's what we have done calculation it says 4.27. Now, based on this formula, at any station, we can write down what is our whirl component, it is

$$C_{w2r} = \frac{constant}{r_r}$$

and β angle at particular station also that we can calculate. It is

$$\beta_{2r} = \tan^{-1}\left(\frac{U_r - C_{w2r}}{C_a}\right)$$

So, at hub if you are considering, we know our hub radius, that's what is coming say 0.1.

So, if you are putting that number it says my whirl component at the hub, it is for, say 42.7 m/s. Our β_2, that's what we are calculating at the hub, it is coming -25.59.

$$At\ hub,$$

$$C_{w2h} = \frac{Constant}{r_h}$$

$$= \frac{4.27}{0.1}$$

$$\therefore C_{w2h} = 42.7\ m/s$$

$$\beta_{2h} = \tan^{-1}\left(\frac{U_h - C_{w2h}}{C_a}\right)$$

$$= \tan^{-1}\left(\frac{25.133 - 42.7}{36.694}\right)$$

$$\therefore \beta_{2h} = -25.59°$$

Same way, we can do our calculation at the tip station, because at tip we know our radius, that's what is 0.2 m, that's what is giving 21.35 m/s. And my β at the tip β_{2t}, it is 38.23°.

$$At\ tip,$$

$$C_{w2t} = \frac{Constant}{r_t}$$

$$= \frac{4.27}{0.2}$$

$$\therefore C_{w2t} = 21.35\ m/s$$

$$\beta_{2t} = \tan^{-1}\left(\frac{U_t - C_{w2t}}{C_a}\right)$$

$$= \tan^{-1}\left(\frac{50.265 - 21.35}{36.694}\right)$$

$$\therefore \beta_{2h} = 38.23°$$

So, you know, the way in which we have done our all parameter calculation, that's what can be done here. So, what we mean is we can do our calculation for α_2, we can do our calculation shall have relative velocities, we can do our calculation for degree of reaction, we can do our calculation for pitch, we can do our calculation for diffusion factor, then we can calculate all angles.

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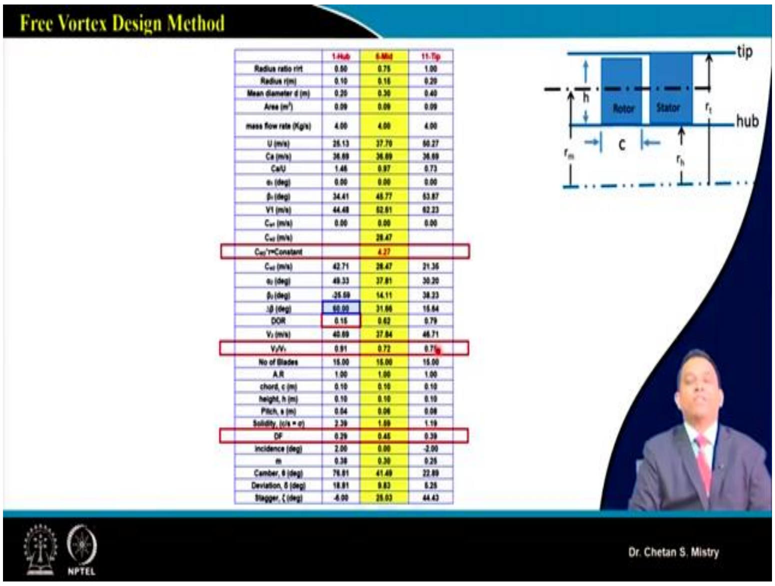

So, let me put it in the compilation form here, okay. So, here if you look at, what we have done? Say, this is what is excel sheet program, that's what we can make or you need to make; make a practice using the excel sheet programming. That's what is little easy and flexible to us when we are doing the design part. So, this is what is our mid-station as we have discussed, and this is what is representing my hub station where our radius is 0.10 and at the tip station, my radius that's what is 0.20, okay.

And this is what is all my calculation at the mid station. If you consider here, this excel sheet program, it is designed in such a way, we can do our calculation for C_w into r at mid-station, that's what is coming 4.27. Now here, in this case, we need to calculate our C_{w2} at the hub station, that's what we have discussed, $\frac{C_w}{r}$. Same way, we need to calculate at the tip, because my constant is known; so, we can calculate what will be my C_{w2}.

Once the C_w is known to us, we can calculate what will be our α_2, what will be our β_2, degree of reaction, velocity ratios. And as we have assumed, our number of blades that's what will not change, that will be 15. So, that's what is aspect ratio is 1, my chord, also we are assuming say constant from hub to tip that is why it is 0.10.

We can say, we can calculate our diffusion factor at hub, we can calculate our diffusion factor at the tip, you can see the variation of this numbers. So here in this case, if you look at, my degree of reaction, that's what is coming 0.15. And as we have discussed first cut check, that's what we need to check with my degree of reaction at the hub should not go 0 or negative. We can say, this is what is reasonable number 0.15 at the hub, it is okay.

Now, here if you look at, my $\Delta\beta$, that's what is coming to be large. We have decided that should not increase 45° but if you recall, when we were discussing different design approach, that time we have discussed, my $\Delta\beta$ for free vortex concept at the hub, that's what will always will come in to be higher. And the reason is not because of any other thing. This reason is because my hub radius and my peripheral speed at the hub, that's what is coming to be lower. And that is the reason why $\Delta\beta$ is coming to be higher.

And here if you look at, as we have discussed, my diffusion factor, that's what is coming to the 0.29 at the hub, 0.45 at the tip, and 0.39 at the tip, and at mid-section it is 0.45, okay. Now, this is what is representing our relative velocity ratio, that's what we said De Haller's factor and that is also coming in a reasonable range.

So, we can say, this is what will be giving us idea about how do we do our calculation at different station. So, at this moment, if we look at, what we have done? Say, we have started calculating our parameter at the mid-station, we have calculated all our parameter at the mid station, that's what is required for making of our blade. Then, once we have understood $C_w \cdot r = constant$, that's what is a law for free vortex, based on that concept, we have done our calculation at the hub station. And based on the same concept, we have done our calculation at the tip station.

Now that hub station we have our C_{w2}, that's what is different at tip station C_{w2} that's what is different and that's what will be giving us idea for calculation of what all parameters we are having. So, here we are stopping with the calculation at three different locations; hub station, mid station and tip station. We are at this moment discussing the design of rotor.

Now, in next lecture, we will be discussing what all we need to calculate at different stations. How do we do our design for the stator. Thank you, thank you very much!