Marine Propulsion

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Lecture - 31
Controllable Pitch Propeller

Welcome to lecture 31 of the course Marine Propulsion. Today, we will discuss Controllable Pitch Propellers.

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The key concepts covered in today's lecture will be Controllable Pitch Propellers, their characteristics performance and applications.

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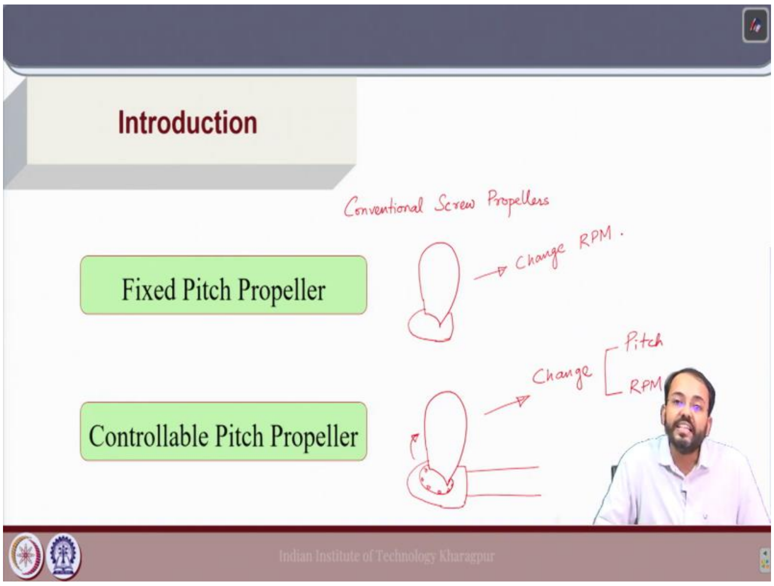

Till now, in this Marine Propulsion course, we have discussed different aspects of marine propellers, starting from the hydrodynamics of marine propellers, blade strength cavitation and some design aspects. So, both open water and behind hull conditions have been discussed. Now, the entire discussions that has been made till now are restricted to fixed pitch propellers; that means, conventional propellers or screw propellers to be more specific. In these propellers, the change of the operation condition for a ship is reflected by a change in the rpm of the propeller.

So, the pitch for the propeller is fixed based on the design value. In the propeller design lecture, we have seen that using suitable methodical series data we can select the pitch ratio of the propeller blade which is the design pitch, based on the design operation condition of the ship and that pitch is the particular value for the specific propeller which cannot be changed, because it is a fixed pitch propeller. So, if we try to draw a blade which is mounted on a hub for a fixed pitch propeller, the blade is directly connected to the hub as an integral structure.

And I have drawn just one blade here, we will have multiple blades depending on the blade number. So, for fixed pitch propellers, we vary the rpm of the propeller to change the speed of the ship. On the other hand, there is another type of propeller which is very popular in the marine industry which is called the controllable pitch propeller. For these specific type of propellers, as the name goes the pitch can be controlled. So, in this type, we have the propeller blade which is mounted on a specific structure and that is connected to the hub here.

And in this particular case, the pitch of the propeller blade can be controlled by rotating the propeller blade on the mount that is used on the hub. Now, in this particular design, the blades are mounted on spindles which are connected to the hub and the blades can be rotated on the hub by changing the pitch of the propeller blades and this can be done by a pitch control mechanism which is typically driven by a piston type mechanism by changing the hydraulic pressure by oil supplied in the propeller shaft here.

And because we have a pitch control mechanism which is housed within the hub, these controllable pitch propellers are slightly more complex in its structure and construction and a larger hub is required to house this pitch control mechanism for the controllable pitch propeller. And in this particular case, we can change both pitch and propeller rpm to arrive at the specific design condition.

On the other hand, for fixed pitch propellers, we can only change the rpm for different operation conditions of the ship. So, these controllable pitch propellers because of their certain advantages, they find applications for specific kinds of ships, where this pitch control mechanism can be utilized for certain operation conditions.

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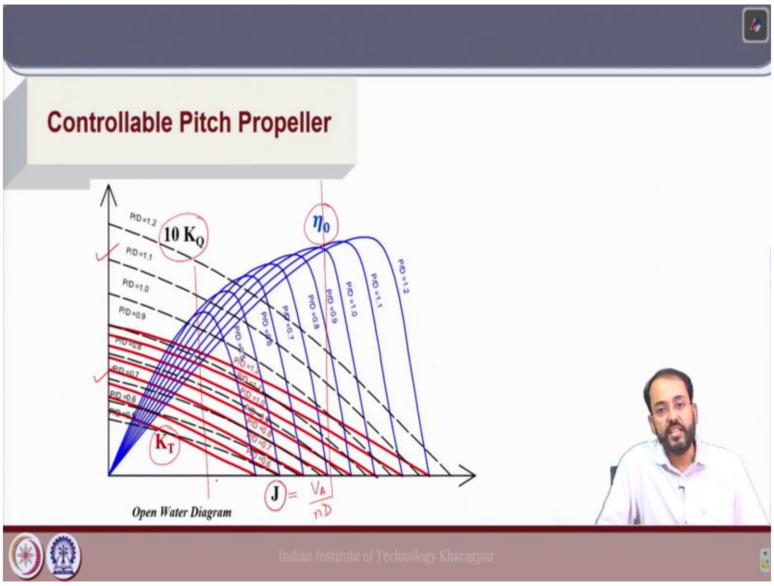

Now, we have seen the effect of variation of pitch on the open water curves for a ship propeller and this set of open water diagrams are given for different pitch ratios for a specific propeller design. Keeping other geometrical factors same, if we change only the pitch ratio and then, we will see that with the J which is the advance coefficient given by

V_A/nD; where V_A is the speed of advance. The thrust coefficient K_T, 10 times the torque coefficient K_Q and η_0, the open water efficiency vary with both J as well as the pitch ratio.

Now, for a controllable pitch propeller, we have discussed that the pitch can be changed in an actual operation condition. So, the propellers are fitted on the hub and depending on the specific condition, the pitch ratio can be changed; that means, the propeller operation curve in the open water diagram will change. So, here, I will briefly discuss the effects of change in pitch ratio on the open water performance which was already discussed under methodical series for propellers.

So, if we have a smaller pitch ratio let us say P/D of 0.7 and it is increased to P/D equals 1.1, then the angle of attack of the section increases. We have seen that for a specific operation condition by increasing the pitch ratio, the section angles of attack will increase and that is how the thrust and torque coefficients will increase. And the open water efficiency will be affected by the change in the thrust and torque coefficients.

So, higher the pitch ratio, the greater will be the region under the open water efficiency curve. But depending on the operation condition, depending on the value of J which gives the propeller loading condition, the open water efficiency will have a specific value. Now, for higher pitch ratios, the open water efficiency is high when we go towards high J values; but if we move towards the lower J values, the lower pitch ratios will give higher efficiency.

So, this forms the basis of changing the pitch for a controllable pitch propeller; that means, in a specific operation condition depending on the thrust requirement, one can change the pitch ratio within a certain range as defined for that specific propeller to achieve different thrust and torque characteristics. And it is done based on the efficiency which is obtained for that specific operation condition.

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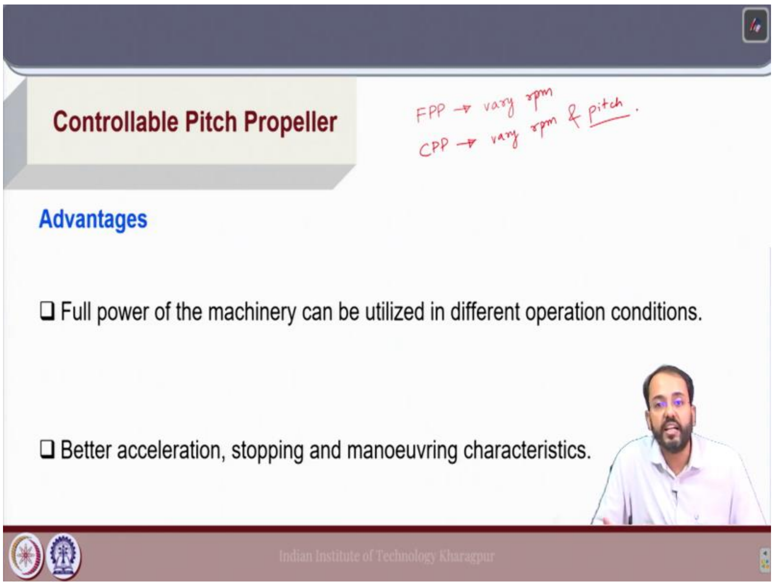

Now, we will discuss some basic advantages of controllable pitch propellers. The first advantage mentioned here is that the full power of the propulsion machinery can be utilized in different operation conditions. So, if we have a fixed pitch propeller, we can only vary rpm. This we have just seen and for controllable pitch propellers CPP, we can vary both rpm and pitch. Now, for some ships, there are shaft driven generators, where there is a requirement to maintain a specific rpm.

So, varying rpm becomes difficult in those cases. Using a controllable pitch propeller, we can go to different operation conditions by varying pitch. So, here we have another degree of independence that to move from one to another operation condition, we can vary the pitch of the propeller blade keeping the rpm constant. Because we have seen that for a diesel engine the power is proportional to the rpm. Now, if we keep the rpm same, then the full power of the machinery can be utilized for different operation conditions.

This is specially suitable for ships like tugs, trawlers, and also other kinds of ships which have multiple operation conditions. Let us discuss the condition for a tug, where there is a towing duty required, where the tug is pulling another vessel and the requirement of power is very high at that condition and also there is a free running speed. Now, in those two conditions having a controllable pitch propeller, where the full power of the machinery can be utilized in both the cases by changing the propeller blade pitch will be beneficial.

Next, having controllable pitch propellers gives greater control over the thrust performance for different conditions and that can be used for better acceleration stopping and manoeuvring characteristics of the ships. Again, these are very much useful for vessels like tugs, ferries and naval ships which require very good acceleration and manoeuvring characteristics.

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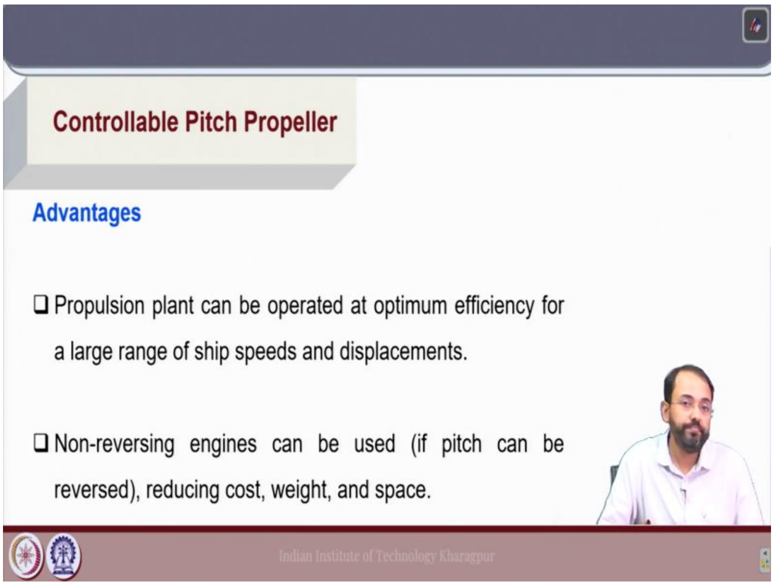

Next, if we have a controllable pitch propeller, the propulsion plant can be operated at optimum efficiency for a large range of ship speeds and displacements. So, it can happen that the displacement can change over different operation conditions and due to change in the ship speeds also, the efficiency of the propulsion plant will change depending on the engine propeller matching, if we have a fixed pitch propeller.

On the other hand, if we have a controllable pitch propeller because we can maintain the rpm of the propulsion plant, it can be operated at an optimum efficiency, which is a positive side for controllable pitch propellers. For controllable pitch propellers, where the pitch can be reversed, we can use non-reversing engines. Now, when we have a fixed pitch propellers, how does the ship move astern by changing the direction of propeller rotation?

Now, the direction of propeller rotation can be changed by reversing the engine rpm. So, a non-reversing engine as compared to an engine which can reverse its rpm will require a lower weight and space and the cost will be lower. So, if we have a controllable pitch propeller, where the pitch itself can be reversed, then we can have a non-reversing engine.

So, there is no requirement for reversing the direction of the engine rotation because the pitch itself can be reversed. Now, there is one more advantage here. We have discussed this aspect of astern motion, when a propeller is rotated in the reverse direction specially, for propellers which have a good amount of skew on the blades, the astern efficiency is very low. Because in that case, the trailing edge becomes the leading edge of the propeller when it is rotated in the reverse direction.

On the other hand, if we have a controllable pitch propeller, we do not need to reverse it. So, just by changing the pitch or reversing the pitch of the propeller blade and rotating it in the same direction, it will produce a reverse thrust. Now, that astern thrust can be used for astern motion of the ship.

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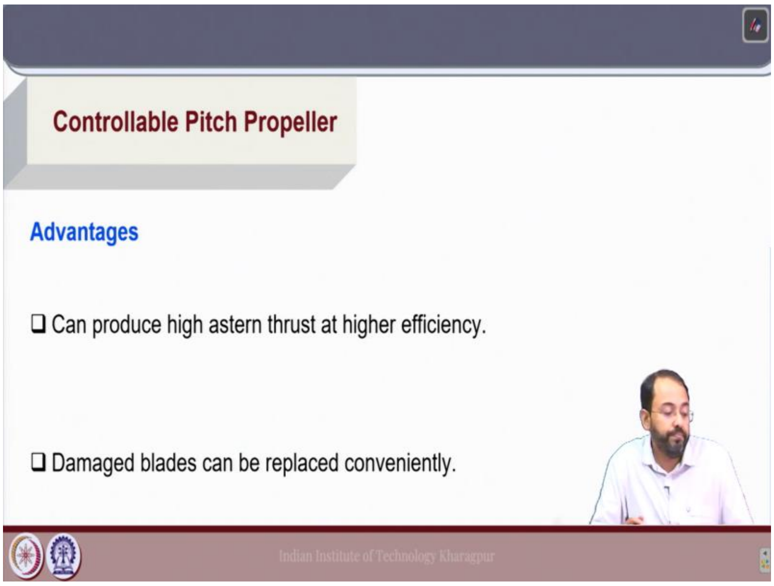

The next point is related to what we have just discussed; controllable pitch propellers can produce high astern thrust at higher efficiency because we are only changing the pitch to produce thrust in the astern direction here. And this is specially, suitable for ships like tugs, trawlers and ferries which operate close to the shore and also, where requirement of astern efficiency is high and also, for naval vessels, where different mission profiles require to have both high propeller efficiency in the ahead running condition and astern manoeuvring.

Here for controllable pitch propellers because each blade is fitted on the hub with respect to a separate structure which can be rotated. So, each of these blades can be individually replaced. So, if there is a damage in any of the propeller blades that can be replaced more conveniently compared to a propeller, where all the blades are fixed to the hub. So, changing one blade will not be possible for those cases, the entire propeller needs to be changed.

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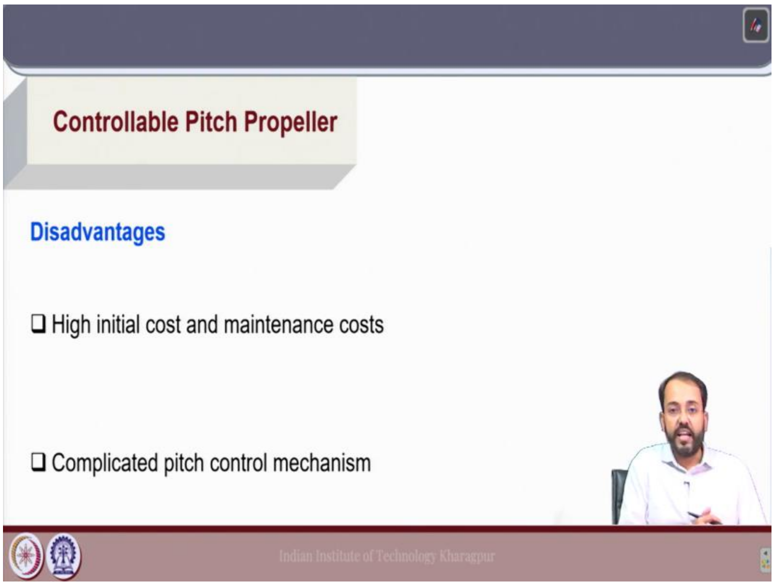

Next, there are some disadvantages which needs to be looked into before controllable pitch propellers can be applied for any specific design application. The first disadvantages mentioned here is the high initial cost and maintenance cost due to a complicated pitch control mechanism. Because we have a pitch control mechanism which requires a hydraulic mechanism and connection to the propeller shaft, it requires a high initial cost to manufacture a controllable pitch propeller and each of these blades needs to be manufactured and attached to the hub separately.

So, the entire mechanism is quite complex and also the maintenance cost is high as compared to a fixed pitch propeller. So, the economics for the particular vessel operation needs to be looked into for designing a controllable pitch propeller.

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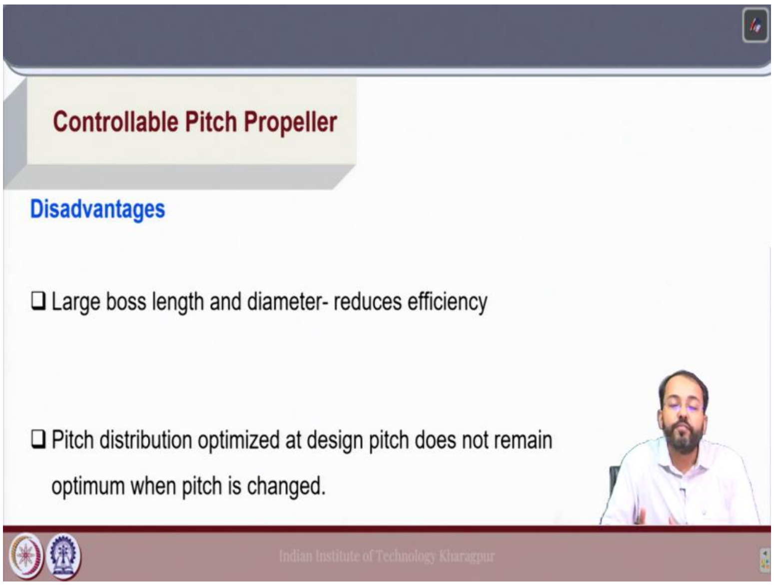

Next, a large boss length and diameter which will reduce the efficiency. For a fixed pitch propeller, we have the propeller blades which are fixed on the hub. Now, because for a controllable pitch propeller, we have the boss housing the pitch control mechanism, a larger diameter, as well as length of the boss, is required. Now, we have seen that it is only the blade that contributes to the propeller thrust. So, the larger the volume or the length and also the diameter for the boss, the smaller will be the available diameter for the propeller blade.

So, for designs, where we need to maintain specific clearance with the ship hull, we have seen that we have diameter restrictions for the propeller blade for specific applications. So, in those cases to have a controllable pitch propeller reduces the available diameter for the propeller blades because of the larger boss diameter will be required to house the pitch control mechanism. And since the available diameter for the propeller blade is lower, the efficiency of the propeller will reduce.

Now, the efficiency is a function of the blade area ratio and we have smaller diameter blades available for the same total available diameter. And hence, the efficiency will be lower as compared to a case, if we had a greater available diameter for the blades. Now, on the other hand, the pitch distribution which is optimized at the specific design pitch does not remain optimum when the pitch is changed.

So, if we design the pitch distribution whether we get it from a methodical series data set or we design using circulation theory, the pitch distribution that is obtained for the design condition will not remain same when the pitch is changed. This aspect will be better explained using a simple problem at the end of today's lecture. So, this change in pitch distribution also affects the efficiency of a controllable pitch propeller.

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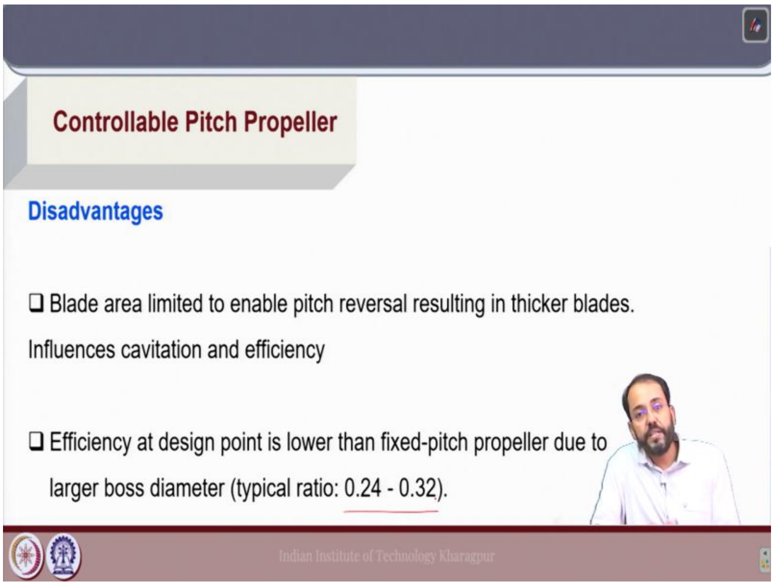

For a controllable pitch propeller, the blades needs to be reversed. Now, each of these blades will be rotated about its own axis on the hub to get a different operation condition. So, for a specific case, when the ship is moving astern, the pitch is reversed. Now, to allow for pitch reversal on the hub, the propeller blades cannot have a very high blade area because the propeller blades need to be rotated on the hub and if pitch reversal is involved, then the blade area is also restricted for controllable pitch propellers.

So, on one side, we have seen the diameter is restricted because of the larger boss diameter and here, also the blade area will be restricted because of the pitch reversal and this affects the efficiency as well as cavitation performance. Regarding efficiency at the design point, if we compare a controllable pitch propeller to an equivalent fixed pitch propeller of the same diameter, what do we see?

The fixed pitch propeller having the same total diameter will require a smaller hub diameter and a controllable pitch propeller on the other hand, due to the pitch control mechanism will require a larger boss diameter; typically in the range of 0.24 to 0.32 times the propeller diameter. And because of this the available area for the propeller blades is less which we have just discussed and due to that the efficiency at the design point for a controllable pitch propeller will be lower as compared to the equivalent fixed pitch propeller which will have a lower boss diameter in comparison.

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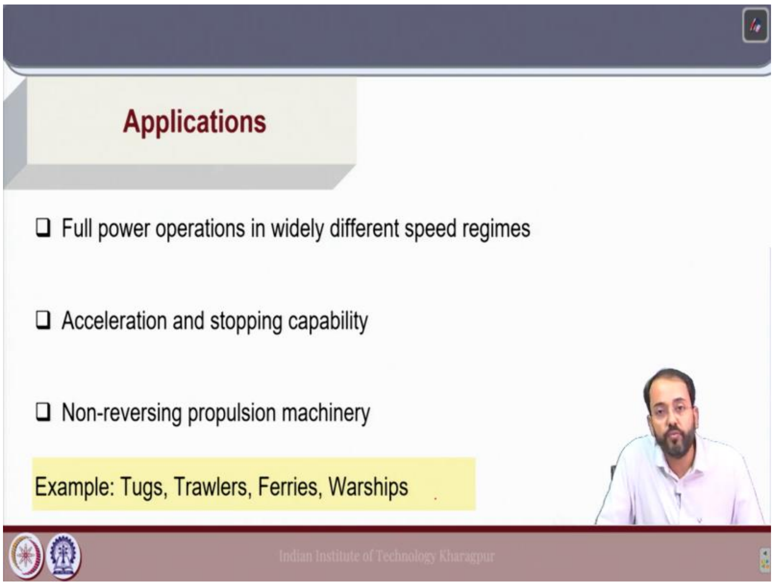

So, based on these advantages and disadvantages, controllable pitch propellers have specific applications, where the advantages are very crucial for the operation regimes of that ship. So, the main applications are for ships were full power operations can be utilized for different speed regimes. Acceleration and stopping capability is very good. Reversed thrust requirement is high; astern performance requirement is high and non-reversing propulsion machinery can be utilized.

So, the examples for such applications are tugs, trawlers, ferries and warships, where controllable pitch propellers are widely used.

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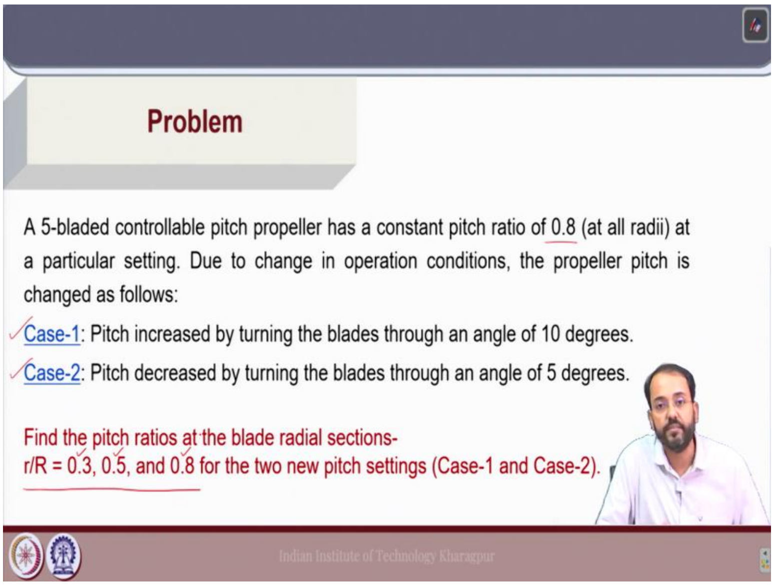

Now, let us look into a simple problem which explains the change in pitch distribution due to the change in the pitch for a controllable pitch propeller. So, in this problem, we have a 5-bladed controllable pitch propeller which has a constant pitch ratio of 0.8 at all radial locations on the propeller blade for a particular pitch setting. So, this specific propeller has a constant pitch ratio for all radial locations on the propeller blade given at a particular setting.

Now, due to change in operation conditions for the ship, the propeller pitch is changed and we have two cases given here. The first case is an increase in pitch by turning the blades through an angle of 10 degrees and the second case is a decrease in pitch by turning the blades through an angle of 5 degrees. So, in this problem, we have an initial condition defined by a specific value of pitch ratio P/D which is constant at all radial locations on the propeller blade.

And then, two cases are defined; in case 1, the pitch of the propeller blades is increased by turning the blades through 10 degrees and in case 2, the pitch is decreased by turning the blades through 5 degrees and it is required to calculate the pitch ratios at different radial locations given here. So, we have three locations at r/R = 0.3, 0.5 and 0.8 for the two new pitch settings.

So, it is important to note that for the original pitch setting which is the initial condition at all the three radial locations, the pitch ratio was 0.8 and in this problem, we will calculate the new pitch ratio for the three radial locations by changing the pitch once by increasing it and once by decreasing it.

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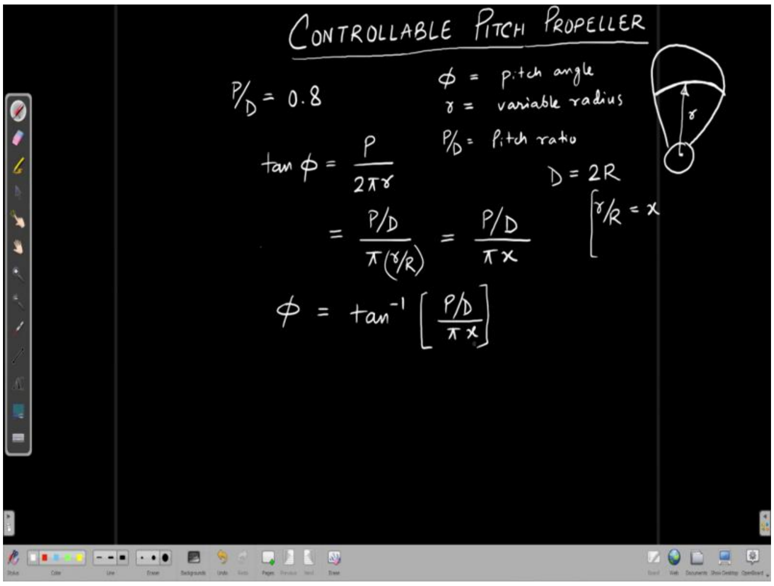

So, in this problem, the initial pitch ratio P/ D is given as 0.8 for all the radial sections. Now, if ϕ is the section pitch angle and r is the variable radius, so if we have a propeller blade and we are taking a section at a radius r and P/ D is the pitch ratio. Then, tan ϕ = P / (2 π r) and it can be written as (P/ D)/ (π (r/R)); where, D = 2R, D is the diameter and R is the radius and if we write r/R equal to x which is the non-dimensional form, then it can be written in this form (P/ D) / (π x).

So, ϕ which is the pitch angle for any particular section can be written as $\tan^{-1}$(P/D)/(π x). In the beginning, we will calculate the pitch angles for the three radial sections which are given in the problem.

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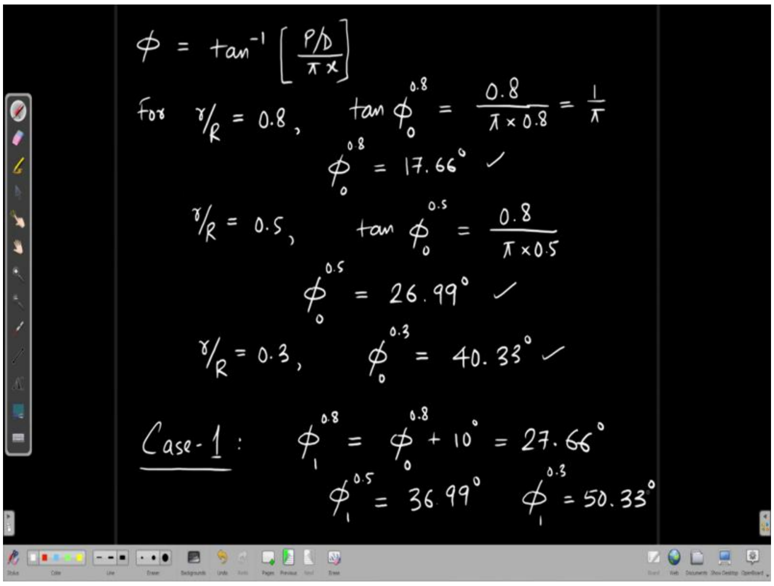

So, for r/R = 0.8, tan (ϕ_0), let us say ϕ_0 is the initial angle is $\tan^{-1}$ (P/ D)/(π x); original P/D was 0.8 / (π 0.8), r/ R = x. So, if we calculate this, we will have ϕ_0. Let us denote it by ϕ_0 at 0.8 because we will have different radial locations. This will be equal to 17.66^0. If we repeat the same calculation for r/R = 0.3, we will see that the initial pitch angle is 40.33^0. Now, it is important to note that as we move from a higher blade radial location of 0.8 r/R to 0.5, to 0.3 for the same pitch ratio, a higher pitch angle will be obtained.

Now, what is mentioned in case one? The pitch of the propeller blade is increased by rotating all the blades by 10 degrees. So, if this is the condition 1, then ϕ_1 at 0.8 radius equals ϕ_0 at 0.8 + 10 degree which is 27.66 degree.

Similarly, ϕ_1 at 0.5 will be 36.99 degree and ϕ_1 at 0.3 will be 50.33^0. So, for the three different radial sections, we have computed the new pitch angle after the blade sections are rotated by increasing the pitch by 10 degrees. Here, we have to calculate the new pitch ratios; the new P/D ratio at the three different radial locations after the pitch is increased.

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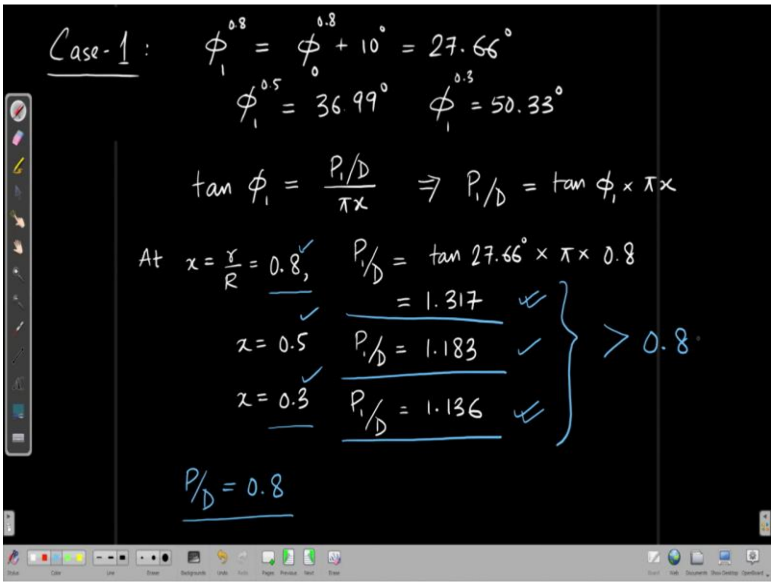

So, again, we can write $\tan\phi_1 = (P_1/D)/(\pi\ x)$. In this particular case, P_1/D is unknown. So, $P_1/D = \tan\phi_1 \times \pi\ x$ ok. So, for $x = r/R = 0.8$, P_1/D will be right and this gives the value 1.317. In the same way at $x = 0.5$ and $x = 0.3$, the new pitch ratio P_1/D can be calculated as 1.183 and here, 1.136. Now, the numbers are important in this specific problem because we are talking about the change in pitch distribution once the propeller blade pitch is changed.

Now, in this problem, the initial pitch ratio P/D of 0.8 was given for the entire propeller blade; that means, for all the three blade sections at the three radial locations x equals 0.3, 0.5 and 0.8, the initial pitch ratio was 0.8. After increasing the pitch by 10 degrees, the new pitch ratios are shown here and we see that the pitch distribution has changed.

So, we no longer have a constant pitch distribution with radius; that means, if we had an initial pitch distribution which was not constant, which was different, we would have a still different pitch distribution after changing the pitch of the propeller blades. And we see that at the radial location which is closest to the blade tip 0.8, we have the highest pitch and at the location which is closer to the hub, we have the lowest value of pitch. All started with the same initial pitch ratio of 0.8 and the increase of pitch by 10 degrees; but the new pitch distribution has changed over the propeller blade.

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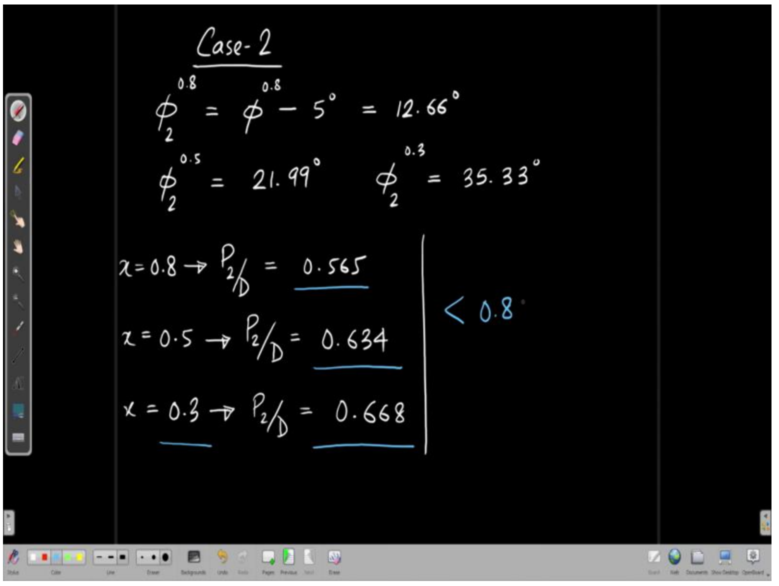

Now, let us look into case 2, where the propeller pitch was decreased by rotating the blades by 5 degrees. So, ϕ_2 at 0.8 will be $\phi^{0.8}$ - 5^0 which comes to 12.66. Similarly, $\phi_2^{0.5}$ = 21.99 degree and ϕ_2 at r/R equal to 0.3 is 35.33 ok. We can use the same concepts to calculate the new pitch distributions for these cases. So, P_2/D at (x = 0.8) is 0.565.

At x = 0.5, we can use the same equation to calculate the new pitch ratio; 0.634 and x equals 0.3, the new pitch ratio is 0.668. Again, because the pitch ratio is related to the tan ϕ, we see that for the same change in the blade pitch angle by reducing the pitch by 5^0, again the pitch distribution has changed for the three different radial locations.

And we see here that at the location which is closest to the hub at x = 0.3, we have the largest value of pitch. The most important thing here is for all the three radial locations, we have the value of pitch ratio which is less than the initial pitch ratio of 0.8 because we have reduced the pitch in case 2. Similarly, if we see for the case 1, for all the three sections, the pitch value is greater than the initial value of 0.8 because the pitch was increased by 10^0.

So, this problem gives a very good representation of the effect of the change in pitch for a controllable pitch propeller on the pitch distribution at different radial locations on the propeller blade. So, if we have a design pitch condition and change the pitch based on specific operation conditions, the pitch distribution on the propeller blade will also change. This will be all for the discussion on controllable pitch propellers.

Thank you.