Marine Propulsion
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Lecture - 28
Propeller Design (Part - I)

Welcome to lecture 28 of the course Marine Propulsion. This will be the first lecture on Propeller Design.

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The key concepts to be covered in this lecture are - the basic approaches for propeller design and some general considerations, which are essential for design of marine propellers.

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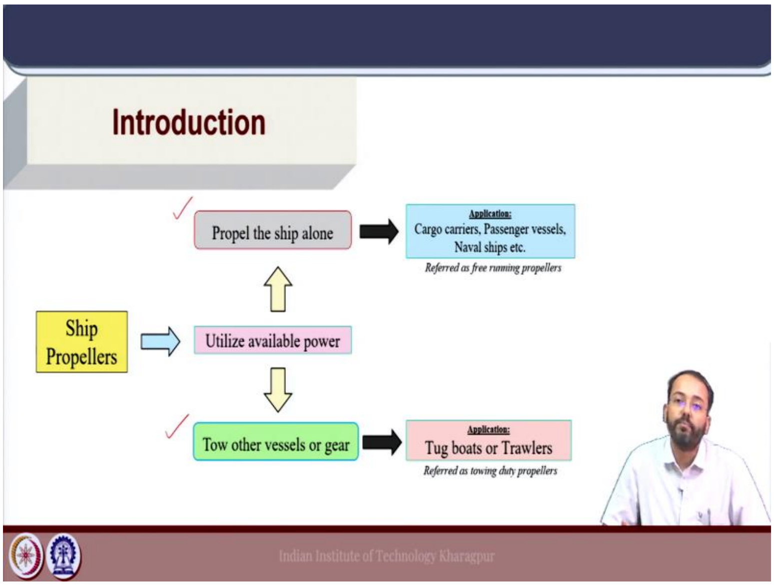

So, if we look into ship propellers; their main function is to utilize the available power, which is delivered from the engine and develop the thrust required to propel the vessel forward. That is the main purpose of ship propellers. And as discussed here we are considering skew propellers. There are other types of propulsion systems for ships which we will discuss in the later lectures.

Here we are considering the marine skew propellers that we have covered in this course, which absorbs the power which is delivered by the engine and provides the thrust for the ship to move forward. Now, this available power which is utilized by the propeller can be used for two different functions, depending on the type of marine vessel on which we are using the propeller.

For example, the first one is to propel the ship alone, which is the primary function for all marine vessels. And the second one here is to tow other vessels or gears, which is special for specific kinds of ships that we will look into. When the power is used to propel the ship alone, this finds its application for different marine vessels like cargo carriers, passenger vessels, naval ships, where the propellers are referred to as free running propellers. That means, the available power is utilized to propel the ship and that is the sole purpose of the propulsion system.

The other application, which is for towing other vessels or gear; this find its application for special kinds of vessels like tug boats or trawlers, where these vessels are used to tow other vessels. That means, the power which is installed for this particular vessels are used both to move that vessel forward along with an additional towing duty, when another vessel is attached to that vessel with a tow rope, and that towing purpose requires additional power requirement and the propeller itself works at a different loading condition.

Because we have learnt that the rpm of the propeller with relative to the forward speed of the vessel gives the loading condition. So, these are special applications for tugs and trawlers, which are referred to as towing duty propellers. So, these two are the primary functions of the propellers, based on their operational scenario of the particular vessel.

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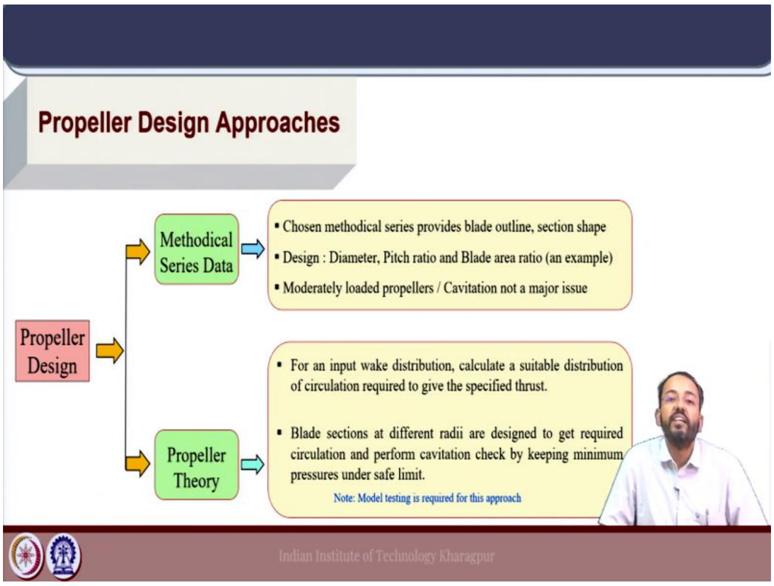

Now, if we look into the different design approaches for marine propellers. There are two basic approaches, which have been used extensively for propeller design. The first is the methodical series based approach, where the methodical series data for different types of propellers are used to obtain a basic design. And the second design approach is to use the propeller theory; that means, mainly circulation theory to develop the blade design at different radial locations and then, the entire blade geometry.

So, if we look at the basic aspects of these approaches the methodical series data as we have studied in the week on propeller open water; certain methodical series have been developed based on basic criteria, which refers to the geometric characteristics of the propeller blades. For example, we have B series propellers, ka series, MAU series, gone series, etcetera.

And each propeller series have a definite set of geometrical parameters by which the series parameters are defined. And based on the requirements of thrust and other operational requirements the series is chosen and then, interpolation is done based on certain parameters to obtain the final design. But here, the idea is that the basic blade outline and the section shapes of the propeller blades are provided by the methodical series.

So, we do not need to make a detailed design of all the blade sections here, because they are already pre defined, when the particular series is chosen. Whether the sections are segmental or airfoil sections that is given by the series itself. So, the design process basically, reduces to the choice of diameter pitch ratio and blade area ratio, which is a typical example and based on this the propeller design is developed.

So, in the series design the process is much simplified, because one does not need to go into designing all the section shapes. And the series charts are used to get the proper pitch ratio and blade area ratio, depending on the propeller operational characteristics and the typical condition that is satisfied is the condition of maximum efficiency given the range of loading in which the propeller is operating ok.

Now, these methodical series data are used to design propellers which are moderately loaded and where cavitation is not a major issue. So, the series data are extensively used for propeller design and even for cases, where one uses propeller theory to develop detailed design; there are often cases, where the propeller designer chooses to go for the propeller theory based design. And even in those cases a firsthand design using a standard methodical series data is obtained to have a basic idea of the design parameters.

So, these series data can be suitably interpolated and for specific geometrical characteristics of the propeller blades, a suitable series based propeller blade design can be obtained; for a good range of running conditions in moderately loaded propellers. Now, if we look into the design process, based on propeller theory. Here one can obtain a much detailed design, which is Taylor made for the specific application.

By specific application we mean that the propeller is operating behind the ship hull and the velocities, which will be the inflow into the propeller depend on the hull geometry; typically, the lines in the stern region of the ship. And hence, the wake distribution, which is the nominal wake; that means the wake distribution on the propeller plane, if the propeller itself was not there.

Just due to the flow around the hull at the specific design speed will impact the propeller performance. And hence, in propeller theory based design one can make wake adapted propellers, which mean that the wake distribution at the propeller plane can be used as an input to develop a much detailed design, which is Taylor made for that specific ship.

Given an input wake distribution, one can attain a suitable distribution of circulation. We have studied some basics of this, under the circulation theory, when a circulation distribution is assumed and after suitable iterations the circulation distribution can be modified using certain constants. And the final distribution, which gives the specified thrust under the required operation conditions can be considered for the design.

And then, at different radial sections of the propeller blade, the values of circulation distributions can be used to design the sections. In this process the propeller designer has a greater freedom as compared to a series design method, because one can choose different types of sections depending on the circulation distribution, which needs to be satisfied, in addition to keeping the minimum pressures under the safe limit.

Why? Because, cavitation checks needs to be performed in a detailed way for different blade sections, so that the cavitation occurrence is avoided in the design process itself. The propeller designs which are developed using circulation theory are new. That means they do not belong to any specific methodical series. So, these designs are typically based on the ship configuration as well as the operational characteristics.

And hence, model testing is a basic requirement for this particular approach; that means, once these designs are developed, model testing needs to be done to estimate the thrust, torque, and efficiency of the propeller developed using circulation theory. Circulation theory based design approach for marine propellers is quite matured now, but still certain progresses are being made to develop the design process and make the parameters involved more realistic. And hence, having model test data to support the design process, once the final design is made increases the confidence in the developed design.

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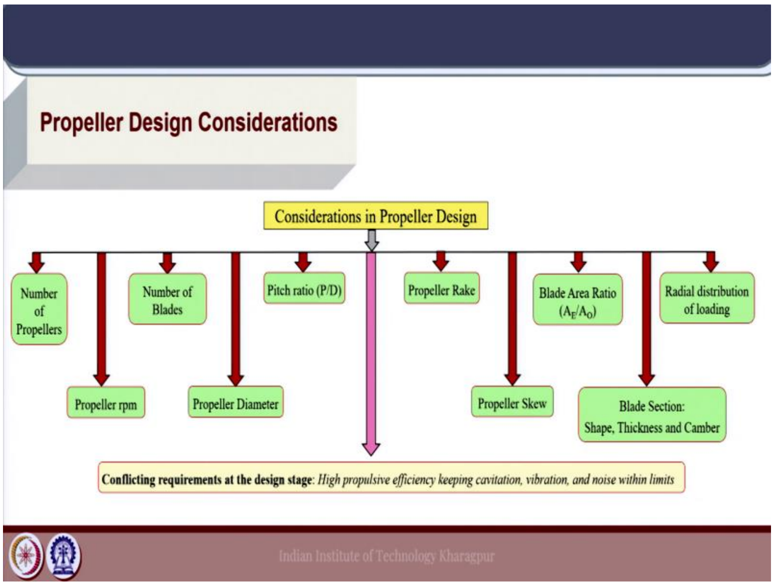

Let us look into some general considerations, which are of prime importance in propeller design. The first consideration here is the number of propellers. Now, for a specific type of vessel based on design experience, often the number of propellers is chosen by default. That means, based on experience of designing similar types of ships based on their operation conditions and thrust loading the number of propellers is chosen.

And we will see that the number of propellers have a very strong influence on the propulsion performance of the ship. Next is the propeller rpm. We have studied that engine propeller matching is a very important aspect of propeller design and also the powering performance of the ship. And hence, the propeller rpm is also extremely important in the design process. We will look into each of these aspects in details as we go on.

The number of blades of the propeller is important in the design process from the point of view of the blade related vibrations and the frequency of operation in relation to the frequency of the hull. So, this is a very important aspect to be considered in relation to the propeller rpm. The diameter of the propeller depends on the available diameter based on the design of the ship and this diameter of the propeller impacts the design of the propeller as well as its thrust loading, for the efficiency calculation of the propeller.

Now, the propeller design depends on the basic set of parameters one of the most important of which is the available diameter for the propeller design. The pitch ratio of the propeller, it governs the blade angles of attack. We have seen from the blade element diagram that for a given set of geometric parameters for example, if we consider a methodical series propeller, where certain other parameters are predefined.

If we change the pitch ratio, what will happen? The angles of attack of the blade sections will increase and changing the pitch ratio changes the thrust, torque, and efficiency characteristics of the propellers. So, the choice of pitch ratio is very important in design. The rake and skew of propeller blades are important, because these parameters are the angles that we see from the side the rake and the skew is the blade shape; which is provided based on the angles at the root and the tip with respect to the vertical line at the center of each of these radial sections.

And these are provided the skew for reducing vibration, because of the wake characteristics in which the propeller is operating. Again we will look into these aspects and rake is provided to increase the clearance for certain cases, for the hull and the propeller. The distance between the propeller blade tip and the hull should be maintained to reduce the propeller related vibrations. And hence, if the diameter is not available according to the proper requirements, then a rake can be provided to increase the clearance.

Blade area ratio again is a very important parameter, because it defines the area, the expanded area as a ratio of the propeller disc area and we have seen that for cavitation calculations the blade area ratio is a important parameter. Next the choice of propeller blade sections is very important. Once we use the circulation theory based design, it is possible to choose the propeller blade sections at different radial locations.

And with regards to blade section parameters the shape of the section, whether it will be an airfoil type section or segmental section that can be chosen and other parameters like thickness and camber, which are also very important in terms of the propeller efficiency, cavitation as well as strength characteristics. So, blade section is a very important parameter for propeller blades.

Now, if we use methodical series propeller design approach, then these blade sections are predefined by the series itself. So, in that case this particular consideration is not available for the designer. Another consideration is the radial distribution of loading. The propeller blade loading changes based on the radial location of the section, where we are calculating the loading, based on the operational characteristics and this is also an important criteria for the propeller design.

Now, we will look into these aspects one by one in more details and how they impact the propeller design process. Finally, it should be mentioned here that, certain considerations which are mentioned here are conflicting in nature. And it is not possible to keep each of these conditions at its optimum level. Finally, it is important to mention that certain considerations, which are mentioned here are conflicting in nature.

And hence, the design should be optimum in such a way that the parameters are chosen to achieve a high propulsive efficiency, because that is the basic requirement for the ship propulsion system and to keep cavitation vibration and noise within certain limits. So, that the performance of the ship and propeller together is optimum.

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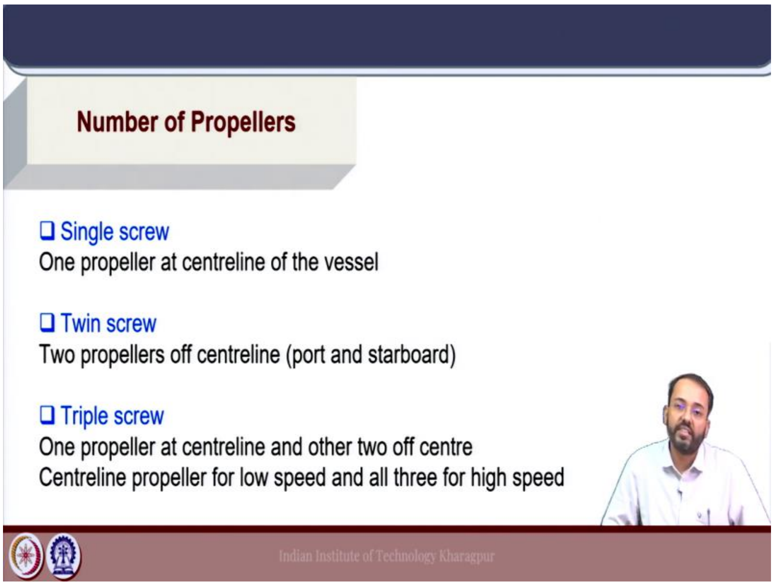

Now, let us look into the first consideration, which is the number of propellers. So, we have discussed different types of vessels like single screw vessels, twin screw vessels. So, if a vessel is a single screw vessel, it has one propeller at the center line of the ship. For twin screw vessels, we have two propellers of center line; one at the port and one at the starboard. And we have discussed this in propeller geometry and how the rotation of the two propellers takes place.

And it is also possible for specific vessel designs, where the thrust requirement is high; then multiple screws are involved. For example, triple screw propellers, where there is one propeller at the center line and the other two at off center positions; one at port and one at starboard. So, in those cases for low speed operation only the centerline propeller is used, and for high speed operations all the three propellers are used.

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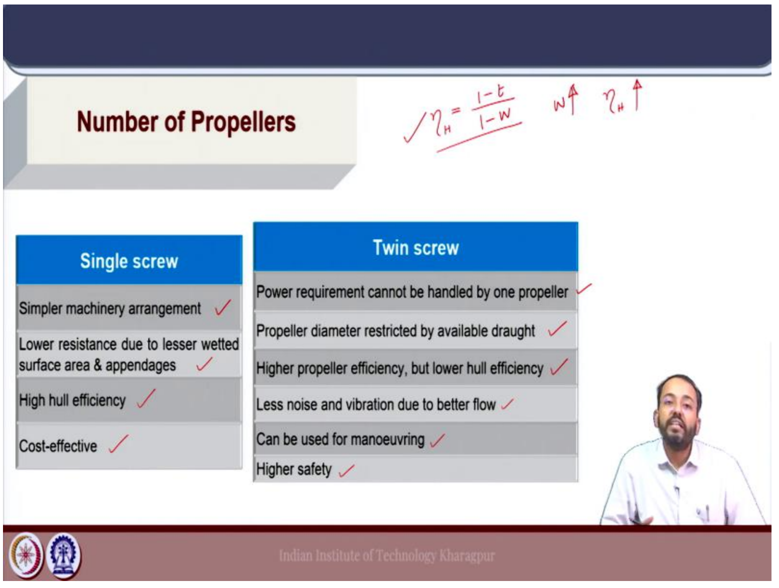

Now, let us look into the aspects of single screw propulsion. That means, if we choose a single propeller to provide the thrust for a particular ship design, what are the characteristics of that design. So, the first thing is we have a simpler machinery arrangement, because the engine shafting and the other supporting structures are only for that particular propeller. So, the machinery system is simple.

We have one engine one set of supporting structures for the propeller and this also leads to lower resistance, because the lesser wetted surface area for the appendages, which are required for the propeller shafting system; for example, the brackets. Each of these supporting structures, they have some wetted surface area and they add up to the total resistance of the ship, which is under the appendage resistance. So, using a single screw propulsion system may help in reduction of these resistance components.

Now, if we write the expression for hull efficiency, it is given by (1 - thrust deduction) / (1 - wake fraction). If we consider a single screw vessel, the velocity deficit is higher due to the blocking effect of the hull at the center plane, where we are computing the wake fraction. So, the wake fraction is much higher for a single screw vessel as compared to a twin screw vessel. Because, wake fraction is higher, it will lead to higher value of the hull efficiency as we can see from this equation.

The last factor here is the solution is cost effective, because we have one propeller and one set of shafting and structures and one engine. So, compared to multiple screw, it will be cost effective. So, if we look into the aspects of twin screw propulsion, the first requirement for which twin screw propulsion is chosen as the primary design condition is that the power cannot be handled by one propeller.

So, if the powering requirement is such that, it cannot be handled by one propeller and it is also in connection to the second point. That means the propeller diameter is restricted by the available draft. If we look into simple momentum theory calculations, the ideal efficiency of the propeller neglecting certain losses is inversely proportional to the thrust loading coefficient.

Now, if we have a high thrust requirement, which is given by this high powering that we are discussing here and also restricted diameter; that means, the thrust loading will be very high on the propeller. So, that will reduce the propeller efficiency. Now, also that will lead to lower pressures at certain regions on the propeller blade, because under cavitation we have studied that if the thrust loading is very high that leads to cavitation occurrence.

So, in these conditions, if the power requirement is high and the propeller diameter is restricted by the draft and vessel design then, twin screw propulsion system is chosen. The third one is a higher propeller efficiency. Now, once we choose the twin screw propulsion system, the thrust loading is distributed between the two propellers. If the total thrust required to propel the ship in a specific operation condition is T.

Then using a twin screw propulsion system the thrust on each propeller is T/2, and that reduces the thrust loading and if the thrust loading is reduced we can obtain a higher propeller efficiency. But, lower hull efficiency is mentioned here because; this is in comparison with single screw. Because the wake fraction for twin screw propulsion system is lower, because the wake fraction is lower the hull efficiency will be slightly low.

Can be used for maneuvering; why? Because, for twin screw propulsion system, we can operate the two propellers individually, and they can be given different speeds and even it can happen that one propeller is rotating in a specific direction to provide forward thrust and another in the same direction to provide reverse thrust. Because in a twin screw propulsion system the two propellers rotate in different directions to balance the torque reactions, both providing forward thrust this has already been discussed under propeller geometry.

Now, we can also use the propellers to produce thrust in two different directions to help in maneuvering the ship in twin screw propulsion system. And also twin propulsion system leads to less noise and vibration due to better flow characteristics on the propeller and hull system and higher safety, because we have two propellers.

So, if there is any damage to one of the propellers and there is still another propeller to provide the propulsion power. So, in that sense there is a redundancy in the system and there is a higher safety in operation.

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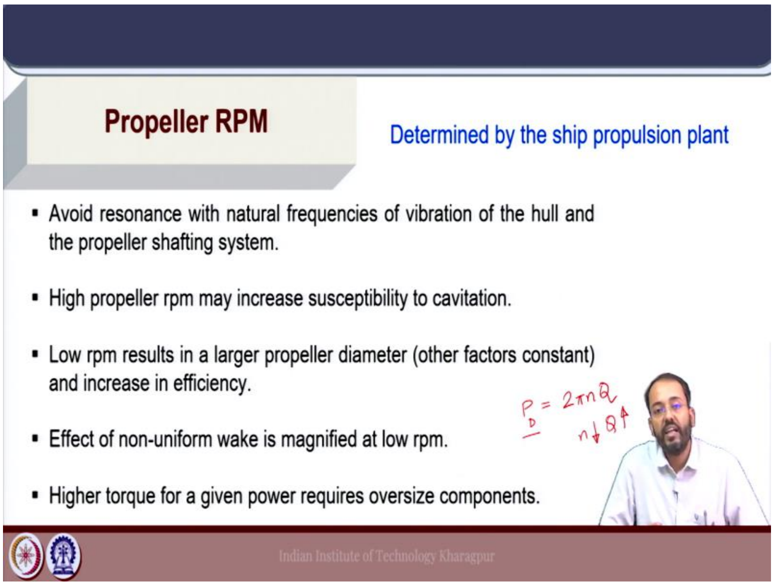

Now, let us look into the next consideration, which is the propeller rpm. This propeller rpm is typically determined by the ship propulsion plant and the matching of the propeller with the particular engine chosen for the ship is very important in terms of propulsion efficiency. And the engine should also perform at its optimum level along with the propeller for a optimum performance of the ship propulsion system together.

Now, the goal here is to avoid the resonance and natural frequencies of vibration of the hull and propeller shafting system.

If the propeller rpm is very high, it may increase the susceptibility to cavitation; why? Because the local velocities around the propeller blade will be very high and there is a probability of the pressure to fall below the vapor pressure in certain locations and we have seen that if proper extent is maintained then, cavitation will occur on the propeller blades. On the other hand, if the rpm is low, then it results in a large propeller diameter and it can help in increasing the efficiency of the propeller; if other geometric factors are same.

Also, at low rpm the effect of non uniform wake is magnified. On the other hand for a given power, if the rpm is low; then what will happen $P_D = 2 \pi n Q$. So, for the given delivered power, if the rpm is low; that means, the torque will be high. And higher torque requires oversize components and this should also be considered while choosing the rpm of the propeller.

So, in general we can say that all these factors govern the design by influencing the design process in different ways. And the optimum choice needs to be done in relation to the other factors that are also involved in the propeller design process; keeping certain criteria within certain limits.

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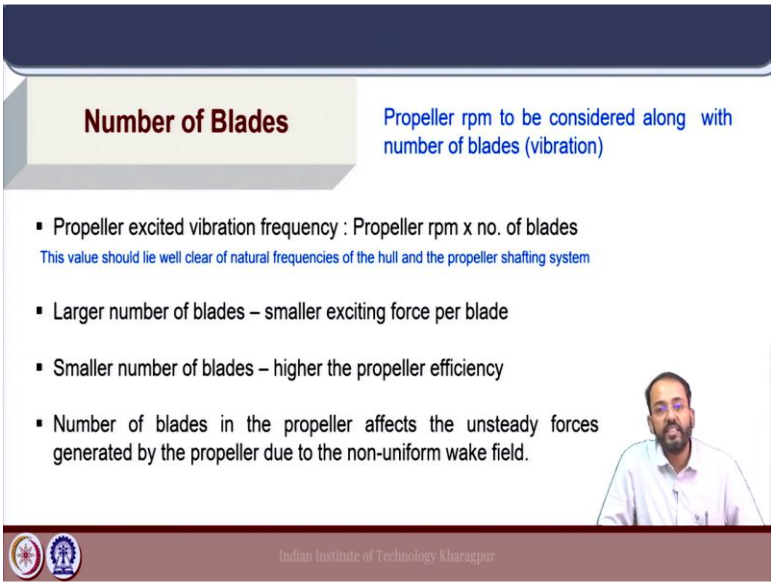

The next parameter that, we will consider here is the number of blades of the propeller. Now, propeller rpm needs to be considered in relation to the number of blades for deciding the propeller excited vibration frequency. Because this is important with relation to the hull vibration frequency and that should be kept within certain difference from the natural frequency of the hull system. So, that there is no resonance in the hull propeller system.

So, the propeller excited vibration frequency is given by the propeller rpm multiplied by the number of blades, which is basically the blade passing frequency. Now, the larger the number of blades the smaller will be the exciting force per blade. On the other hand, the smaller the number of blades the higher will be the propeller efficiency. So, this is where the conflicting conditions arise. On one side, if we have the smaller number of blades that will increase the propeller efficiency.

On the other hand, if the propeller blade count is high, then the exciting force per blade will be low. And the number of propeller blades in the propeller also will affect the unsteady forces generated by the propeller; especially, in the non uniform wake field behind the ship. So, these considerations should be important in deciding the number of blades in the propeller design. So, this will be all for today’s lecture. We will continue with other considerations in the next lecture.

Thank you.