Marine Propulsion
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Lecture - 19
Engine-Propeller Matching (Part - I)

Welcome to lecture 19 of the course Marine Propulsion. Today we will discuss Engine Propeller Matching.

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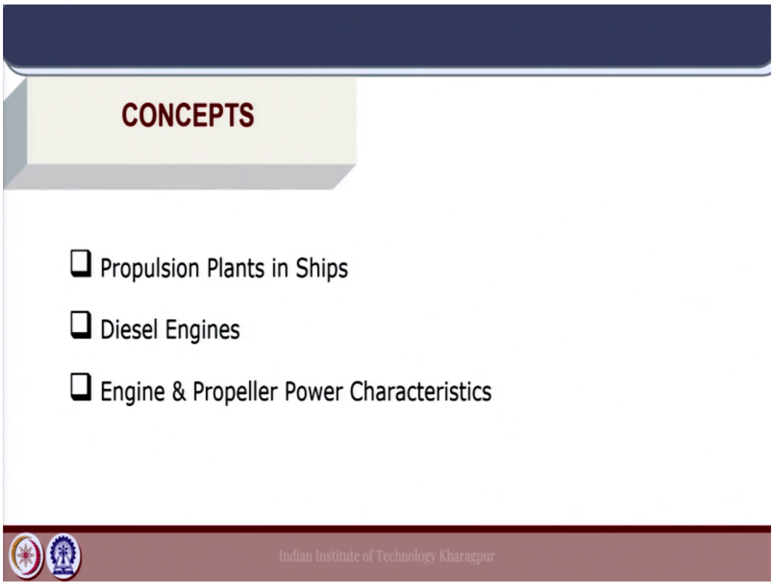

So, the key concepts covered in today's class will be a short discussion on propulsion plants used in ships. The main form of propulsion which is very popular for merchant going vessels, which are diesel engines and the concept of power characteristics for both engine and propellers. This will provide the basis for engine propeller matching which are used for powering calculations.

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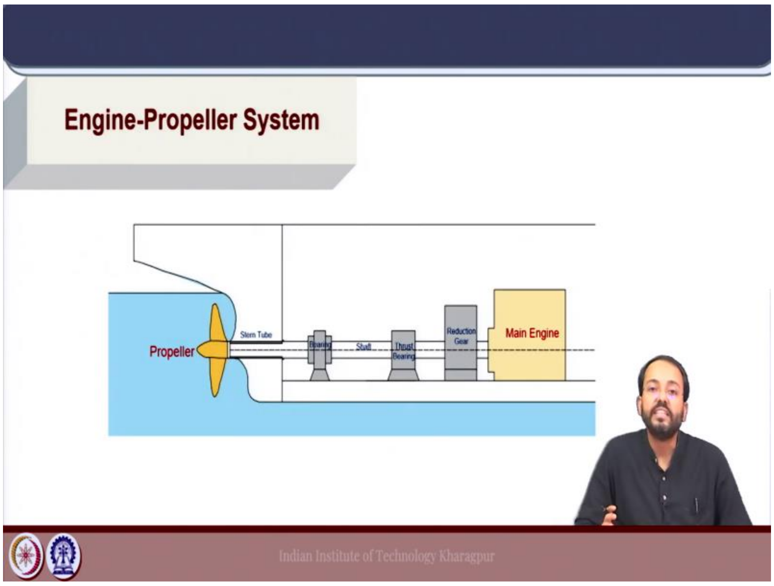

This diagram shows the engine propeller system for a ship which was shown in hull propeller interaction class and here we have the main diesel engine which is connected to the propeller via a shaft. And there is a reduction gear shown which I mentioned is optional depending on the type of engine and the thrust bearing is transmitting the thrust which is generated by the propeller to the hull. So, now we will move on to the different types of engines or propulsion plants, which are used in ships.

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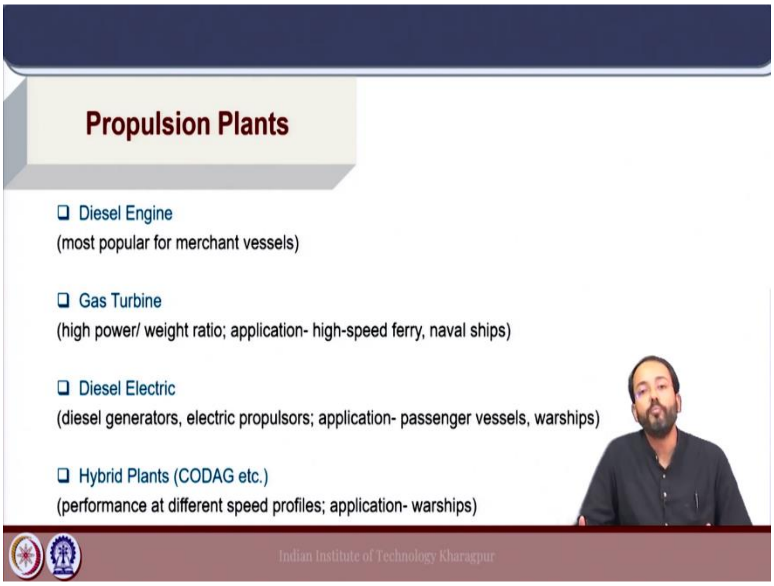

So, the most popular propulsion plant used for marine vessels, typically for merchant ships is the diesel engine. There are many types of diesel engines which we will discuss and which are used for specific purposes and they are the most widely used form of propulsion plants for ships. The next type is gas turbine, which is used for ships which require higher speeds, typically high speed ferry and naval ships because these gas turbines have high power by weight ratio, which is useful for high speed vessels.

Diesel electric propulsion plants are used in certain passenger vessels, warships, they have diesel generators which are connected to electric drives which basically drive the propulsors. And we have hybrid propulsion plants like CODAG which is basically a combination of diesel as well as gas turbine. These are used in vessels which have multiple operation profile.

Typical application is a warship, different kinds of naval ships which have more than one operation profile at which it needs to perform optimally. So, these speed regimes can be easily met with a combination of diesel as well as gas turbine. So, this is one example, there are other kinds available for also hybrid type of propulsion. Now, apart from this there are other propulsion plants for example, steam turbines which used to be a very popular form of propulsion historically which have been replaced by these forms with the development of electric propulsion.

These units are also being used for specific type of vessels, like ferries where batteries are used as a reserve power source. And other form of propulsion plants may also include nuclear propulsion which are typically used in naval submarines.

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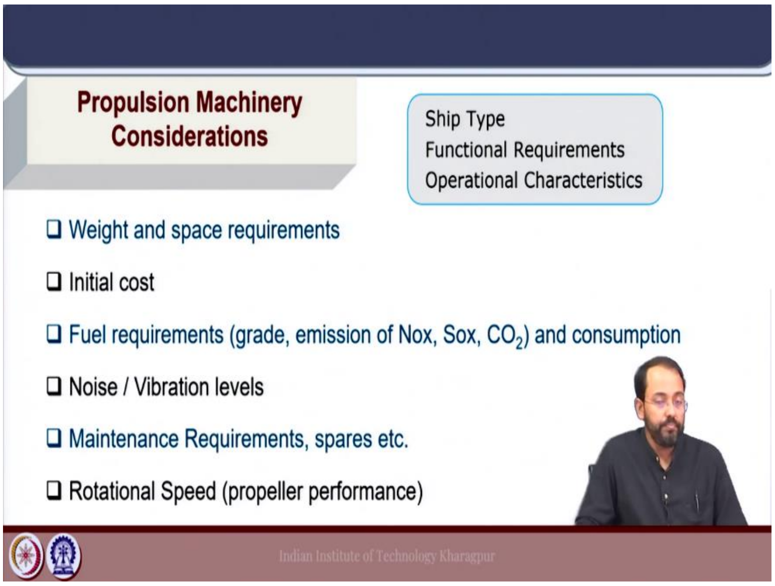

Now, what are the considerations which are taken into account for choosing a particular propulsion point for a ship? The primary consideration is the weight and space requirement which is very important for specific vessel types. There are certain other considerations like the initial cost which defines the economy of operation for a specific kind of ship. The fuel requirement, the grade of fuel the emission of greenhouse gases and consumption of fuel for engine types is important to define the operational perspective of that vessel type.

The noise and vibration levels will depend on the type of engine which is chosen. The maintenance requirements, availability of spares these are also important parameters. And finally, the propeller performance with which the engine needs to be matched, the rotational speed of the propeller with respect to the engine capacity will be important to design the or choose the machinery with respect to a specific ship type. So, the shift type as well as the functional requirement and operation characteristics will be important in the choice of the propulsion machinery for a specific ship type.

Now, we will look into diesel engines for this specific course which will basically cover the main aspect of engine propeller matching as included in this particular lecture. Another aspect which needs to be mentioned here is, in the international shipping industry a paradigm shift is expected from the point of view of autonomous shipping. Because there will be a certain degree of autonomy for different kinds of vessels in future which is expected to operate in the global waters.

In that case the choice of propulsion machinery will also be important from the point of view of autonomous ship operations.

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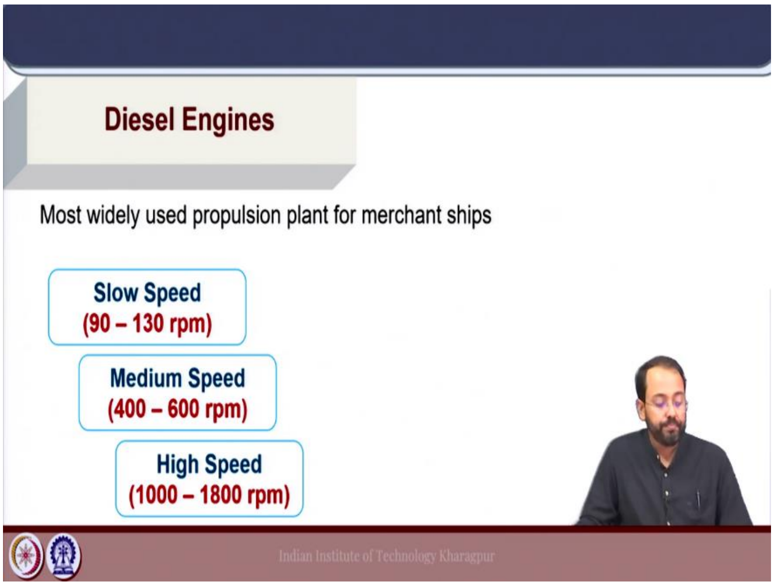

Now, if we go to diesel engines, there are main three kinds of engines which are being used for ships. So, diesel engines are the most widely used propulsion plants for merchant ships and the main kinds of diesel engines which are being used belong to three different categories. Slow speed, medium speed and high speed.

Basically, the differentiation is based on the engine rpm. So, for slow speed diesel engine the range of rpm is typically between 90 and 130, for medium speed diesel engine it is between 400 to 600 rpm and for high-speed diesel engines the rpm is very much on the higher side between 1000 and 1800 rpm typically.

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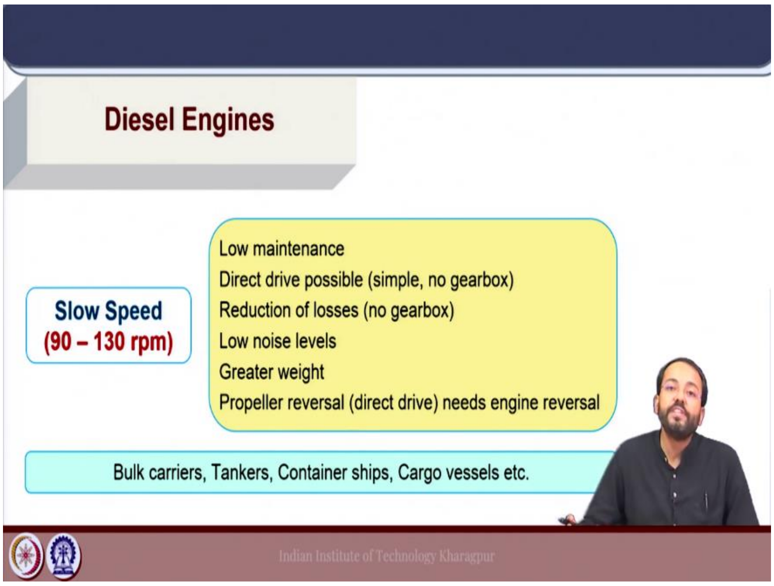

So, if we look into the aspects of slow speed diesel engine these are low maintenance and very simple arrangement because the engine is directly connected to the propeller. So, direct drive is very much possible here and there is no gearbox involved. So, the engine being directly connected to the propeller, the rpm of the engine will be same as the propeller here.

So, we can save a small part in the losses where we have the gearbox losses which is considered in the shafting loss, when we discussed hull propeller interaction. Here considerably we can have low noise levels because this is a slow rotating engine, but the weight will be quite high for these kinds of diesel engines. And the propeller reversal because it is direct drive will require the engine to be also reversed during Aston operations.

So, these are the main characteristics for low-speed diesel engines which makes it an optimum choice for large carriers, typically merchant ships like bulk carriers, tankers, container ships and large cargo vessels. So, the propulsive efficiency can be quite high using the combination of direct drive with slow speed diesel engines. So, which makes it an optimum choice for large cargo vessels like bulk carriers and tankers.

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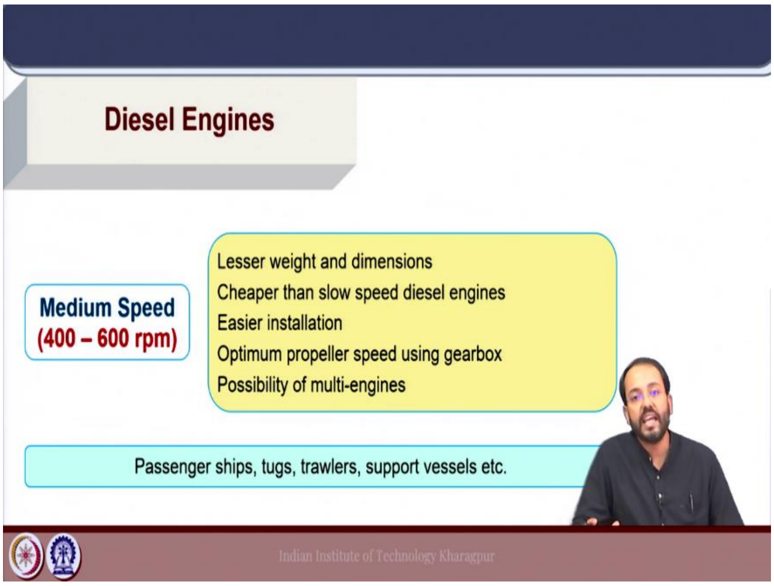

Next the medium speed diesel engines which operate in the range of 400 to 600 rpm in general. So, the weight in this case is lower and the dimension also smaller compared to slow speed engines. They are cheaper than slow speed diesel engines and installation is easier because of smaller dimensions.

Because the engine speed is quite high here 400 to 600 rpm as compared to the typical propeller speeds the gear box is essential here which can be used to connect the engine to the propeller and the propeller speed can be adjusted accordingly. And possibility of multi engines is also here for medium speed engines. For applications these are typically used in passenger ships, tugs, trawlers and support vessels where medium speed diesel engines can be quite useful in terms of their operational characteristics.

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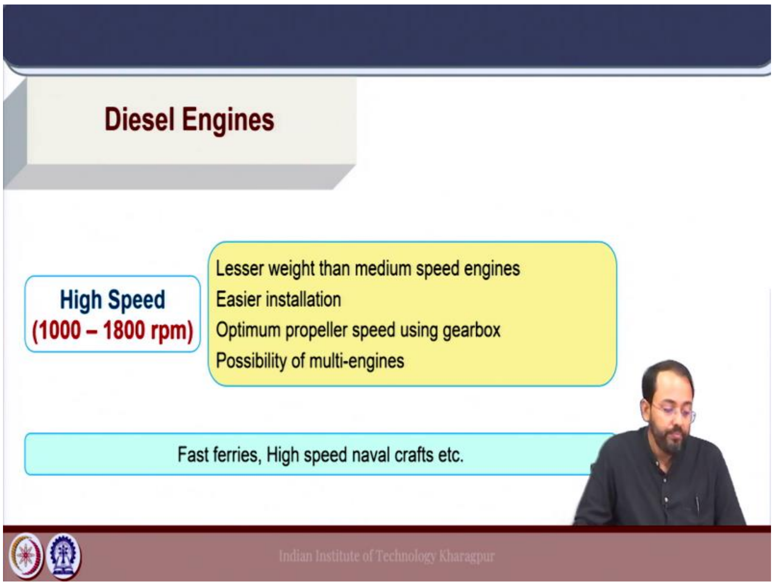

Next, high speed diesel engines which have very high rpm typically higher than 1000 the weight is lower than medium speed diesel engines and also the dimensions will be smaller. Installation will be easier again because the speeds are quite high as compared to the propeller rpm, the gear box comes into play here and possibility of multi engines is also there. Now, they find their applications in high-speed crafts typically fast ferries and high-speed naval crafts, where these high-speed diesel engines are being used.

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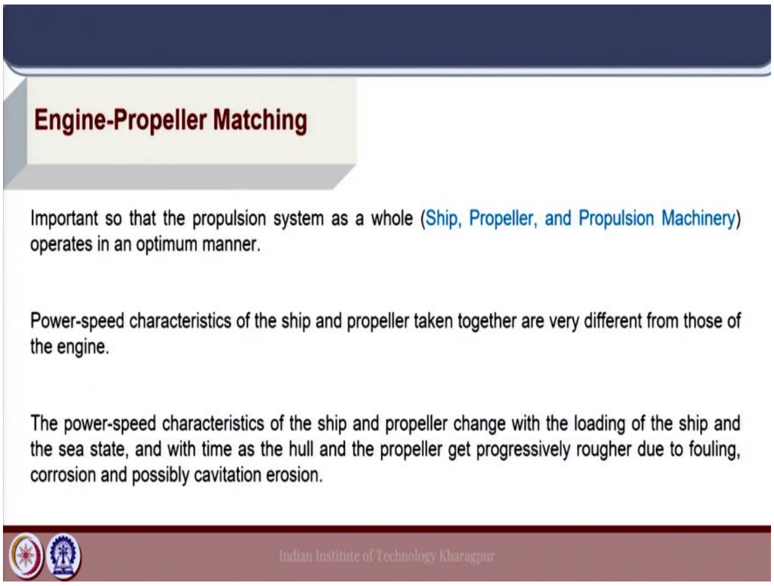

Now, if we come to the main discussion of this lecture which is about engine propeller matching, it is very essential for the propulsion system which includes the ship, the propeller as well as the propulsion machinery to operate in an optimum manner. So, the matching of the engine with the propeller is very important here. In the hull propeller interaction, we have seen that the propeller design is very essential with respect to the specific hull design and the stern design of the ship is also important for the propeller characteristics. Because that defines the wake field into the propeller.

Now, similarly here the propulsion machinery or the engine here is very important, the choice of the machinery or the engine is very important in defining the engine propeller matching for a particular ship. Now, the power speed characteristics of the ship and propeller are very different as compared to that of the engine, which we will see now. Because of that the matching of the propeller with the engine is very essential.

Also the loading of the ship depends on the sea state and with time the hull and propeller gets rougher due to fouling corrosion; in fact, cavitation may also happen because of that there will be a change in the power demand from the ship side. But the engine is already installed, the engine characteristics is based on the choice of the engine. But with time, with age the power characteristics of the ship will change.

Due to fouling, corrosion and also during the operation of the ship, due to sea state the power speed characteristics of the ship and propeller system will change. So, these things needs to be identified and properly matched with the engine characteristics so that the entire system can perform in an optimal manner.

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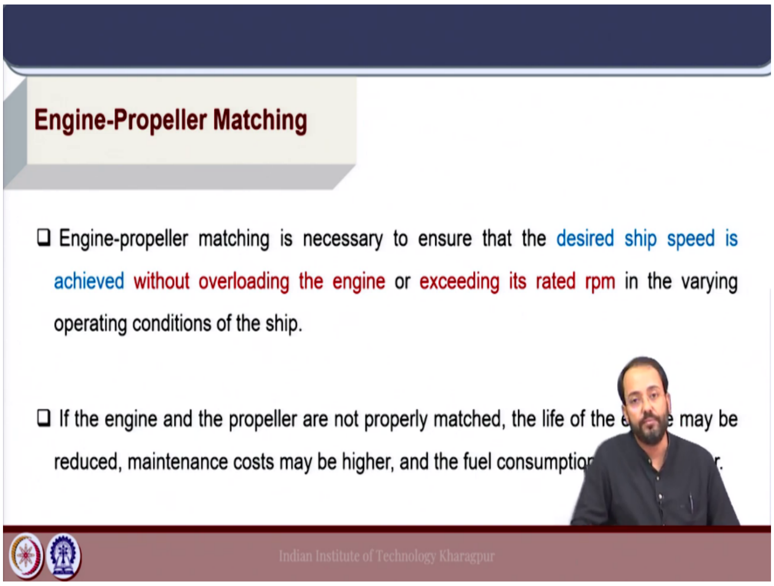

Now, the engine propeller matching needs to ensure that the desired speed is achieved without overloading the engine or exceeding its maximum rpm for varying operation conditions of the ship. If they are not matched properly what can happen? The engine life span may be reduced because of sub optimal operation conditions and also maintenance costs may be high, the fuel consumption may be high which will affect the economy of the vessel.

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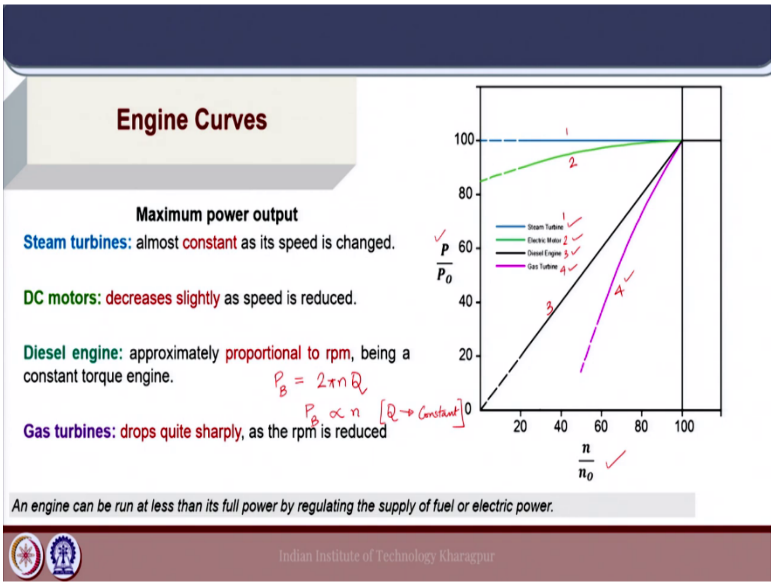

Let us now look into the engine power curves. We have discussed different kinds of engines some of them will be covered here. So, for steam turbines, the power is basically almost constant the maximum power even if the engine speed is changed. So, here in the plot shown on the x-axis we have the engine speed the rpm as a function of the maximum speed. So, n / n_o which is the maximum speed and here similarly we have power as a ratio of the maximum power so that these vary from 0 to 100 percent ok.

So, the power is plotted as a function of rpm for different kinds of engine. First, we have for the steam turbine, this curve 1 where the power the maximum power is almost constant with the change of speed. For DC motors, the power is reduced slightly as the speed is reduced, number 2 here. Next, for the diesel engine which is the most widely used propulsion plant for ships the power is approximately proportional to the rpm.

The third one here diesel engine, the power is proportional to the rpm. So, it can be assumed to be a constant torque engine, because $P_B = 2 \pi n Q$. So, if P_B is proportional to rpm, then the torque is constant for diesel engines. And for gas turbines it is observed that the power drops quite sharply, number 4 here as the rpm is reduced. So, depending on the type of engine the power dependence on the rpm will vary.

Again, in this particular course, we will concentrate only in the matching of engine and propeller for the diesel engine. So, if we make a general conclusion for different kinds of engines, the engines can be run at less than its full power by regulating the supply of fuel or electric power as required for that specific type of engine.

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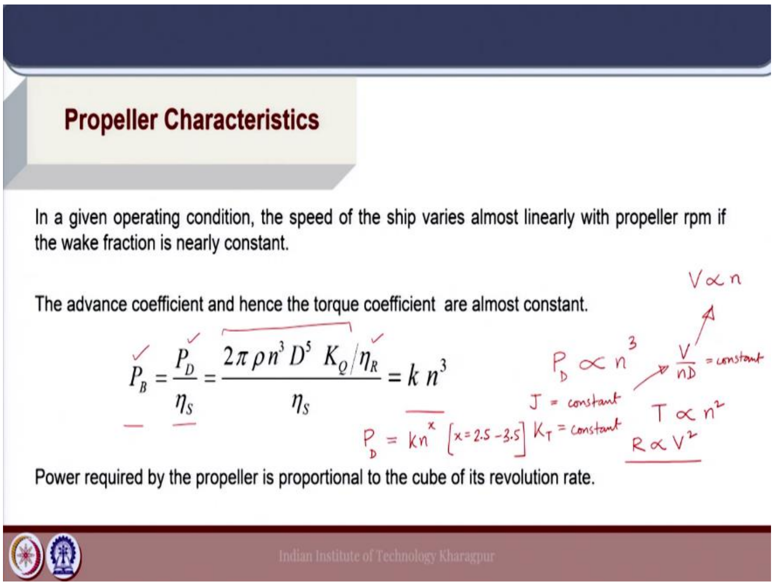

Now, let us consider the propeller characteristics. What is the nature of the propeller with respect to the relation between the power and the rpm? In general, it can be expressed as a cubic function that the power is proportional to n^3, we can write $P_B = k\, n^3$. Now, what is the logic behind this and what are the implications? So, for a particular operation condition it is observed that the ship speed is almost linearly varying with the propeller rpm.

If we take into consideration that the wake fraction is almost constant for a specific operation condition. Now, the advance coefficient and also the torque coefficient are almost constant for a specific operation condition. Now, the delivered power P_D divided by the shafting efficiency will give the brake power of the engine and this delivered power is given by 2 π n multiplied by the torque and that expression can be written in this form where K_Q is the torque coefficient.

If that K_Q is written as the open water torque coefficient, we have this η_R relative (Refer Time: 17:38) efficiency coming. Now, here we see that if K_Q is constant, P_D can be expressed as $k\, n^3$ so that power delivered at the propeller is proportional to the cube of the rpm. So, if K_Q is taken as constant, the advance coefficient in that operation condition range will also be constant.

If that advance coefficient is constant J will be constant and K_T will also be constant. For K_T to be constant, the thrust will be proportional to n^2. Then we can write again assuming that there is not much change in the thrust deduction, the resistance will be proportional to velocity square. Because J is constant means V / nD is constant, then velocity will be proportional to n.

Now, considering that the thrust deduction does not change much, we can write that finally, the resistance will be proportional to the velocity square. Now, this is a reasonable assumption for a specific displacement range considering a particular ship type. Now, this delivered power proportional to n^3 for a propeller which is typically called the propeller law, does not hold true for all conditions. In general, it is observed that this power delivered to the propeller can be expressed as k n to the power x, where x is in the range of 2.5 to 3.5.

So, for practical calculation purpose, we generally take n equal to 3, where P_B is expressed as k n^3 for engine propeller matching calculations.

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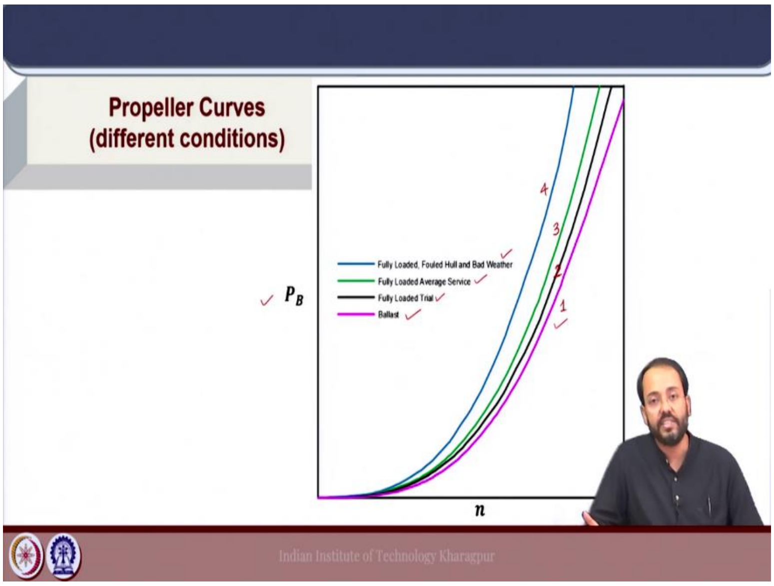

Now, the propeller depending on the operation condition will have different power demand. So, the if P_B is the brake power calculated from the propeller side, it will depend on the operation condition of the ship. The ballast condition of the ship will require the minimum power being delivered at the propeller and also that can be taken forward to calculate the brake power of the engine P_B, ok.

So, we are calculating the power from the propeller side here, the propeller curves are shown for different operation conditions of the vessel. So, the condition which requires the minimum power, the pink line here is the ballast condition, number 1. Next will be the fully loaded trial condition, the trial condition for a ship is where the trial is done just after the ship is newly built in a controlled environment, where the sea is not rough and the wind and other weather conditions are within a particular limits and the ship is new.

So, the power requirement for the trial condition will be lower compared to the service condition. So, the fully loaded trial condition will be next number 2. The green line is the fully loaded average service condition, which is the power demand for the ship in average service depending on the service profile and the operational characteristics of the ship, the green line. The power requirement in this will definitely be higher than the trial condition.

And the fourth case, the blue line is the condition for fully loaded fouled hull and bad weather. This is the worst condition that is expected for a ship operation, where the ship is fully loaded, the weather is bad, the sea condition is rough and the hull is fouled. That means, after years of operation the hull has undergone fouling and the power demand will be highest as compared to the other conditions. Hence, in these four conditions the propeller curves will be very much different and the powering demand with respect to rpm is shown for all these four conditions.

Now, this is a set of propeller curves for a specific propeller and ship combination. And in doing engine propeller matching, we have to compare and match with respect to the engine characteristics.

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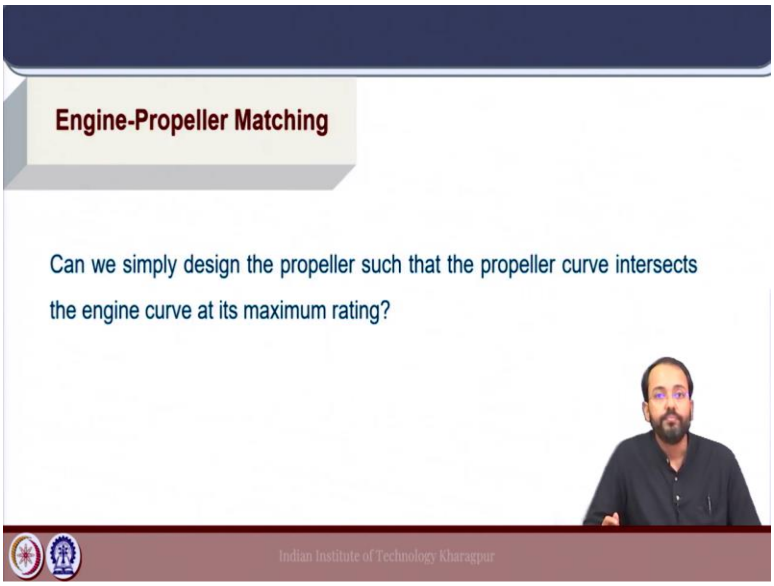

So, the question here is very simple, can we design the propeller such that the propeller curve intersects the engine curve at its maximum rating, because any engine will have a maximum rated power. Can we just design it simply by matching the propeller curve to intersect the engine curve at its maximum rating? The answer is not that simple because we have a set of operational requirements and the engine curves that we will see will form an envelope, depending on the operation of the engine the limits of operation will be guiding that envelope.

And the propeller curves have to be matched considering the different operation conditions of the ship. So, this is what we will continue with in the next class, the matching of the propeller power curve with the engine curve and providing certain margins in the powering process. So, this will be all for this class.

Thank you.