Marine Propulsion
Prof. Anirban Bhattacharyya
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

Lecture - 20
Engine-Propeller Matching (Part - II)

Welcome to lecture 20 of the course Marine Propulsion. We will continue with Engine-Propeller Matching.

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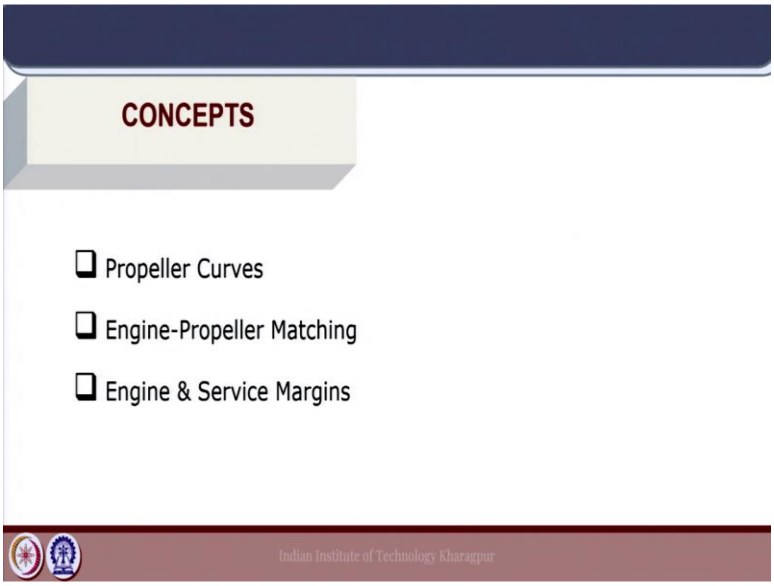

The key concepts covered here are propeller curves, the power curves for different conditions of propeller operation; engine propeller matching, the matching of the propeller curves with the engine curve for diesel engine and the margins considering the engine propeller matching, which are engine and service margins.

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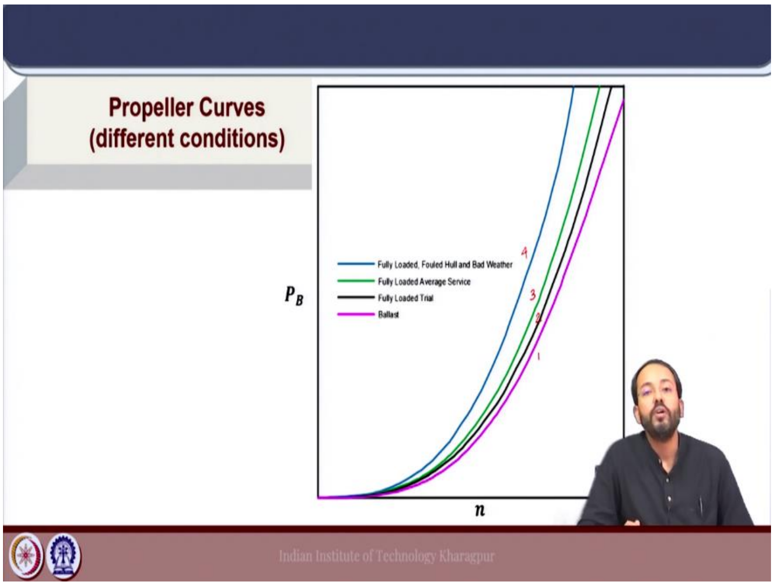

So, we have discussed different propeller curves for different operation conditions for a ship. We have the ballast condition for which the power demand is lowest, the first curve from the bottom here. Next, we have the fully loaded trial condition, the black line where the powering demand will be higher as compared to the ballast condition.

Next, we have the fully loaded average service condition, the green line which is basically the power demand for average service condition of that specific ship type and finally, the highest demand case, where we have fully loaded fouled hull and bad weather condition, where the power demand for the propeller will be highest.

And for propellers, we have seen that the power demand can be expressed as k multiplied by n^3; that means, the power demand or the delivered power to the propeller is proportional to the cube of the propeller speed and for diesel engines we have seen that it is typically constant torque type. So, the power for diesel engine is directly proportional to the rpm.

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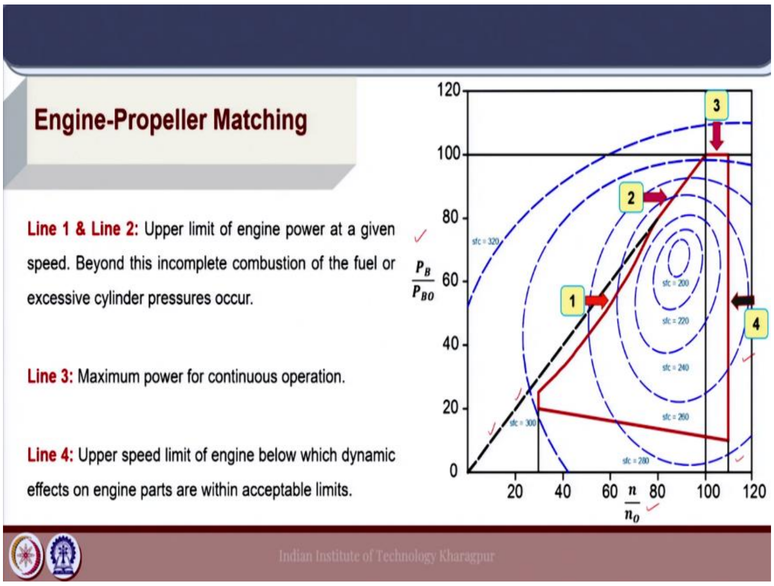

So, now, we will look into the engine operational diagram and we have to fit the propeller curves on this diagram to perform engine propeller matching. So, this is basically the operational characteristics of a typical diesel engine, where again on the y-axis the power is shown as a fraction of the maximum power. So, 0 to 100 P_B by P_{BO} which is the rated power and in the x-axis, we have the rpm. And because this is a constant torque engine, the black dotted line here represents the relation between the P_B and the n for constant torque.

Now, this red envelope shows the operational limits of the engine with respect to certain performance characteristics. We will look into these one by one. So, we have the lines 1 and 2, which represent the upper limit of engine power for a given speed. Beyond this, the combustion of fuel will be incomplete or excessive cylinder pressures may also occur.

So, these lines 1 and 2 provide the upper limit of engine power for a specific engine speed. Line 3 is the maximum power for continuous operation. Line 4 towards the right is the upper speed limit of the engine; if we go beyond that there will be dynamic effects which will not be acceptable.

So, the upper speed limit is the limit below which the dynamic effects of the engine parts will be within the acceptable limit and if you notice this line 4 is corresponding to a higher value of rpm as compared to the rated rpm. So, this is the maximum permissible limit for a specific operation period, it is allowed.

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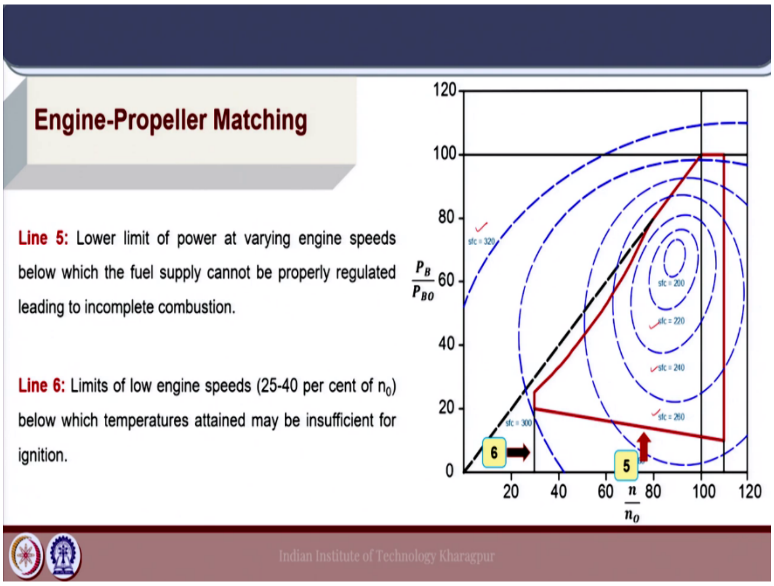

Line 5 is the lower limit of power at varying engine speeds. So, this line gives the lower limit below which the fuel supply cannot be properly regulated, which will lead to incomplete combustion of the fuel and the performance of the engine will not be proper. And finally, line 6 is the limit of low engine speed below which the temperature attained will not be sufficient for ignition.

So, these lines form a closed envelope in which the engine operation is within the acceptable range and we have to match the propeller performance curve, the power versus rpm for the propeller on the engine performance diagram that we have just seen and in this particular diagram, the sfc value for different locations on the engine envelope is shown. sfc is the specific fuel consumption of the engine.

So, the specific fuel consumption of the engine will depend on the location on the engine envelope operation, where we are computing the power characteristics.

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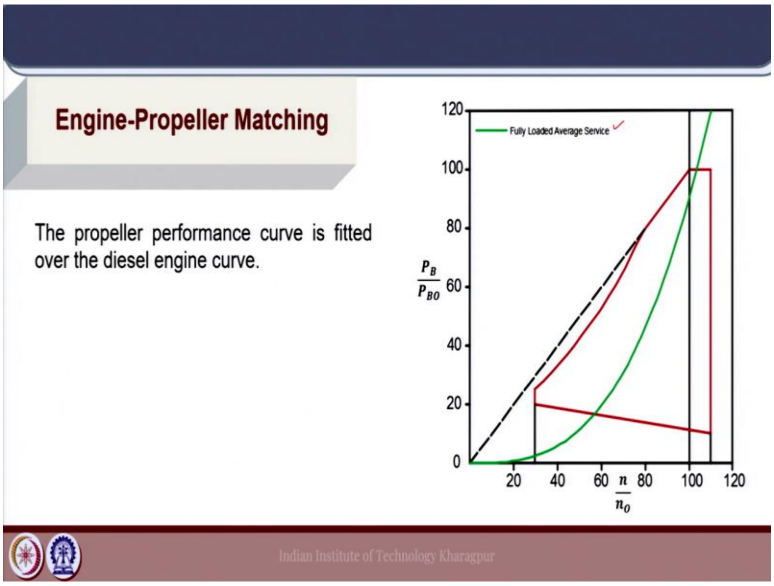

So, for the propeller power curve, the condition of fully loaded average service is taken and that propeller curve is juxtaposed on the engine performance curve. The reason for choosing this will be discussed later, when we talk about the margins and in this way we have to understand the relation between the propeller power demand and the power generated by the engine when we do the engine propeller matching.

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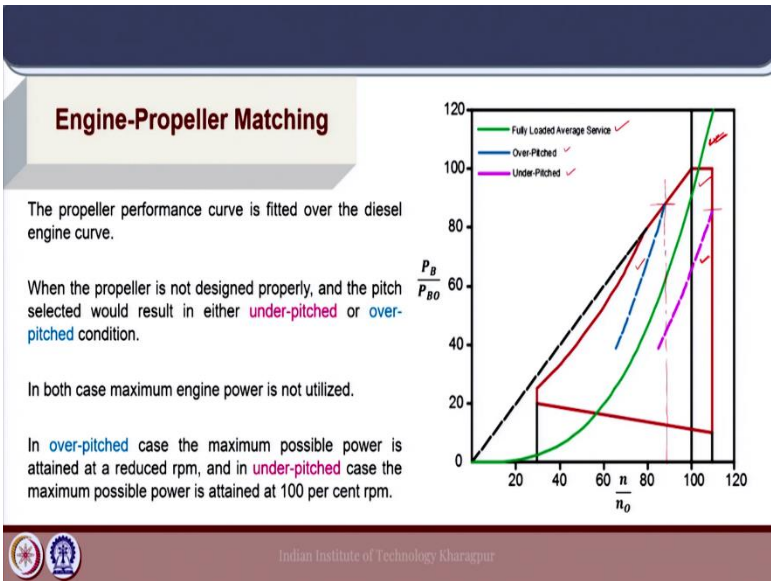

Now, let us assume that compared to this condition, we have two different conditions which are shown; an over-pitched and an under-pitched condition. So, let us say that if the propeller is not designed properly; that means, the pitch choice which is very essential, we have seen that the pitch of the propeller blade governs the power that is being absorbed by the propeller because change of pitch changes the inflow velocities and the angle of attack. And hence, the thrust and torque for the propeller blade and which finally, will change the power absorption characteristics of the propeller.

So, if the pitch is not properly chosen, for example, if it is under-pitched or over-pitched we have taken two scenario. So, if it is under-pitched, the pink line here. So, it will absorb less power as compared to the optimal design which is the green line. This one is for the fully loaded average service condition, the green line.

So, if it is under pitched, it will absorb less power. So, the pink line is below the green line. On the other hand, if the pitch selection is on the higher side compared to the optimal value, then the power demand will be higher which is the blue line; the case for over pitched.

Now, what will happen? In both these cases, the maximum engine power will not be utilized. Why? Because if we look into the over-pitched condition, here the maximum possible power is attained below the maximum possible rpm so, at a reduced rpm value, here we are getting the maximum power, which is lower than the maximum power that we could have achieved if the propeller was designed at the proper pitch with the fully loaded condition the green line ok.

On the other hand, if it is under-pitched, the pink line; then what happens? The maximum power is only achievable at higher rpm. In both these cases, this is lower than the maximum power that is obtained from the green line ok. So, we see that if the propeller pitch choice is not optimal compared to the requirement for a specific operation condition, the maximum power of the engine will not be utilized.

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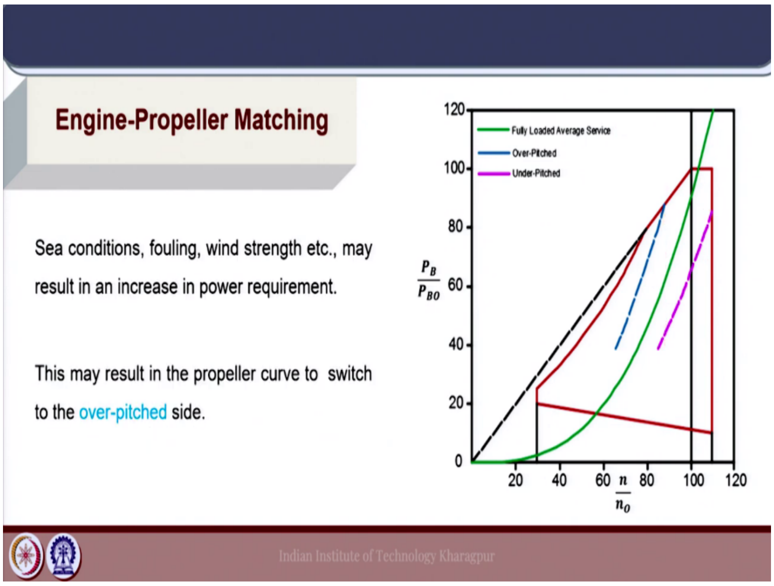

On the other hand, the sea condition fouling wind strength etc., they play very strong role in the power demand for an ship. So, basically what they do is the power demand for a ship increases because of these conditions, which are applicable for different operation scenarios of the ship. Because of this increase what happens that the propeller power curve is basically shifted. The optimal curve that would have been if we do not consider rough sea condition fouling will be low compared to if we consider these conditions.

So, this will result in the propeller curve to be shifted slightly to the over-pitched side; that means, the power demand will be slightly higher. So, these needs to be taken care of in the engine propeller matching and that is why we see that the service conditions are very important in engine propeller matching for a specific ship type.

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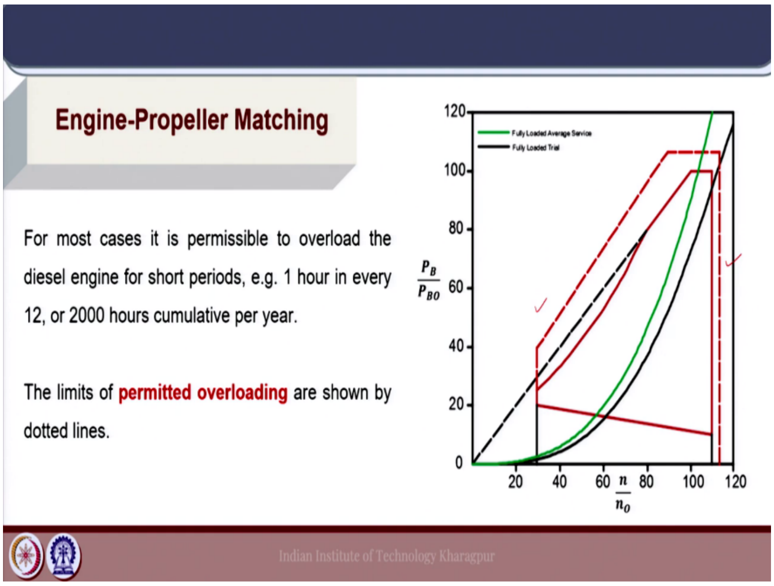

Now, for most cases, it is permissible to overload the diesel engine for very short period; that means the diesel engine can be operated beyond the maximum rated values. So, overloading is applied, but for only very short period; that means, 1 hour in every 12 hours as a standard or 2000 hours in a cumulative way per year.

These limits of permitted overloading are shown by dotted lines in this figure ok. So, we have the standard envelope, which corresponds to the operational conditions and these borderlines governing this envelopes are already discussed. Apart from that, we have this dotted lines, which are basically showing the permitted overloading conditions for an particular engine type ok. But these are only for short duration.

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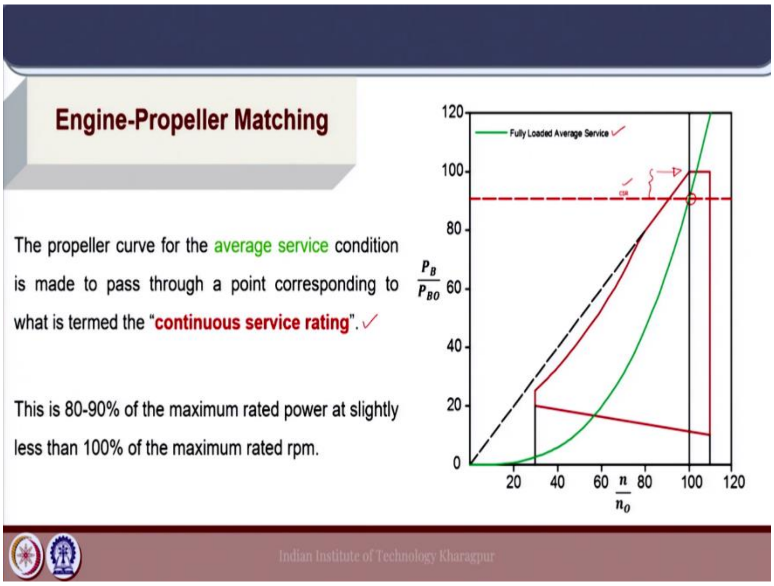

Now, what is the basis of engine propeller matching; how do we place the propeller curve in perspective to the engine curve? This is the question which I had asked in the last class and the basis for that will be the continuous service rating. What is typically done here is the average service condition of the propeller curve is taken.

So, we have the fully loaded average service condition, the green line from the propeller curves and this is made to pass through a point which is called the "continuous service rating" CSR mentioned here for the engine, such that it is slightly lower than the maximum rated engine power value shown here ok.

So, in general, this is around 80 to 90 percent of the maximum rated power and slightly less than the maximum rated rpm of the engine ok. So, this is the basis of matching the propeller curve in the average service condition with respect to the maximum rated engine power ok. By doing this, we maintain a margin here which is the difference between the maximum rated engine power and the continuous service rating.

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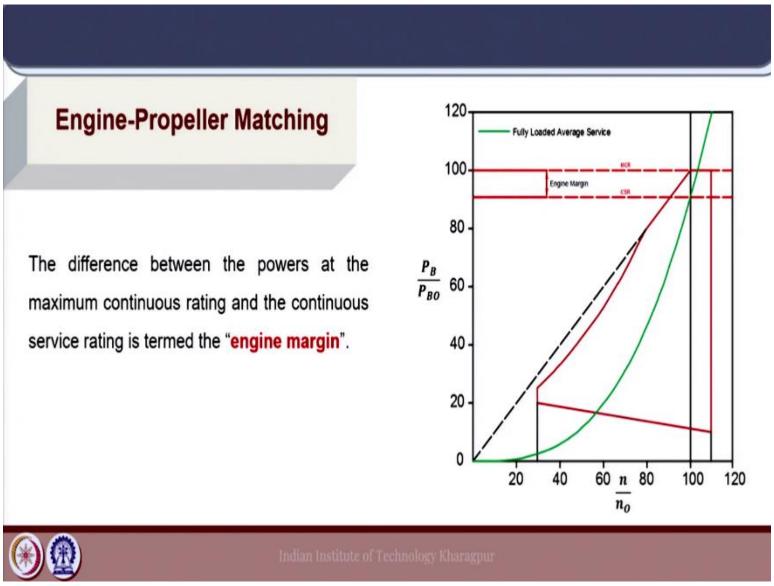

This margin is called the engine margin. So, the maximum rated condition is the MCR of the engine and the continuous service rating CSR is the point, where this fully loaded average service condition intersects with the engine curve which is slightly lower than the maximum continuous rating. So, the difference between them is called the engine margin ok.

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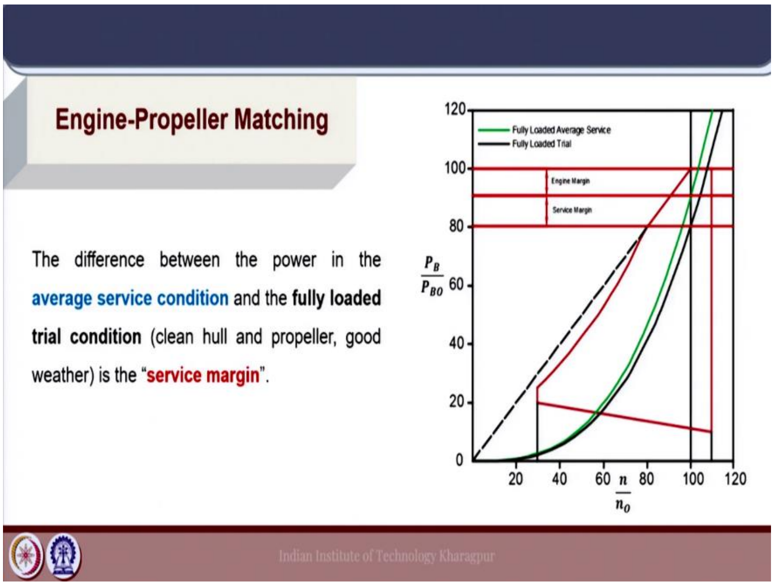

Now, there is one more margin which is required. Basically, it is the difference between the power demand in the average service condition and the fully loaded trial condition. So, in these set of curves, we add the next condition for the propeller which is the fully loaded trial condition in addition to the average service condition, which is already shown.

So, the difference between the intersections of these two curves, the green line and the black line on this vertical is called the service margin. Why? Because the average service condition of the ship will depend on the operational scenario and it is an average over the lifetime of the operation of the ship. Hence, the power demand in the average service condition for the propeller will be much higher as compared to the power demand in the trial condition that we have already seen.

And a service margin needs to be provided because with time, the ship hull will become fouled and the service condition will basically require more power because of the wind and wave scenario and the operational demand depending on the ship operational criteria will be different from the powering in the trial condition, because it is a very much idealistic condition controlled environment and the ship is newly built for the trial condition. So, these two margins are very essential for the ship powering process.

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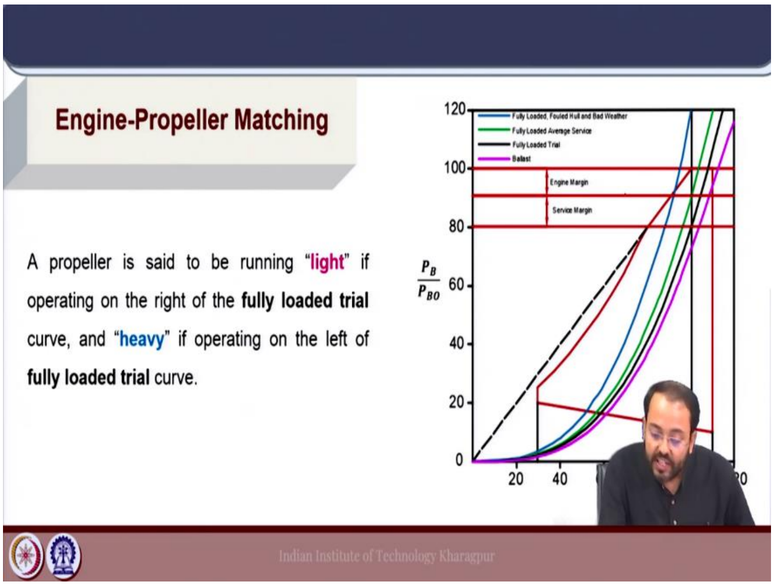

Now, if the propeller is operating on the right of the fully loaded trail curve; that means, we have this black line which is the fully loaded trial curve, if the propeller operates to the right of that curve; that means the powering demand is lower than the trial condition that is considered as a light running condition.

That means, the propeller power demand of the ship is lower than the trial condition, then it is running light. On the other hand, if the propeller is running towards the left of this trail curve. So, we are taking the black line as the reference then towards the left is the heavy operation condition; that means, the propeller is operating heavy.

So, the power demand in this condition is higher than the fully loaded trial curve ok. So, now, all the four curves are shown here and we can see that as we go from the ballast to the fully loaded trial average service and fouled hull bad weather, the power demand of the propeller increases and it intersects the engine curve at different points.

So, for example, if we take the blue line, we have what we have seen already previously in the over-pitched condition, basically which is the condition for very high power demand and it will fall outside the range of the maximum engine power and we can only achieve a part of the maximum power that too at a lower engine speed ok. Now, these engine and service margins will depend on certain factors that we will see now.

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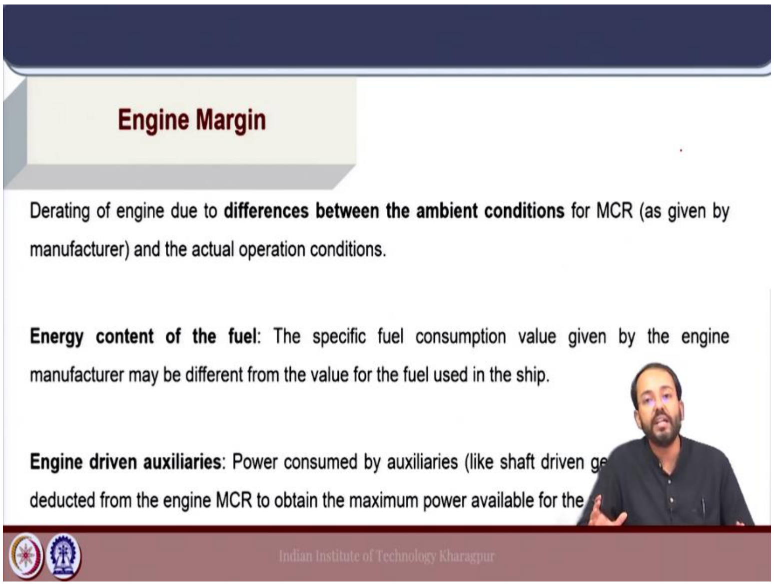

An engine is normally de-rated by providing a margin because the ambient condition at which the MCR is defined the maximum continuous rating is defined by the engine manufacturer is different from the actual operation condition. That is valid for all ships ok. So, the actual operation condition is very different from the condition at which the engine rating is done by the manufacturer.

So, that is the basic reason for providing a margin. The next is the energy content of the fuel. The specific fuel consumption value, the sfc values that we have seen in the charts are given by the manufacturer for a specific condition and the fuel type may be slightly different when it is used in the ship.

So, that energy content of the fuel will be an important factor for providing an engine margin and the last one also depends very much on the operation of that specific ship type which is the power consumed by auxiliaries. Now, in certain ships there are auxiliaries, which are used along with the main engines and these take power from the engine.

For example, shaft driven generators, now they require power additionally from the engine which is on top of the propulsive power which is required by the propeller because of that, engine margin has to be provided and accordingly, the total engine margin has to be decided depending on all these conditions.

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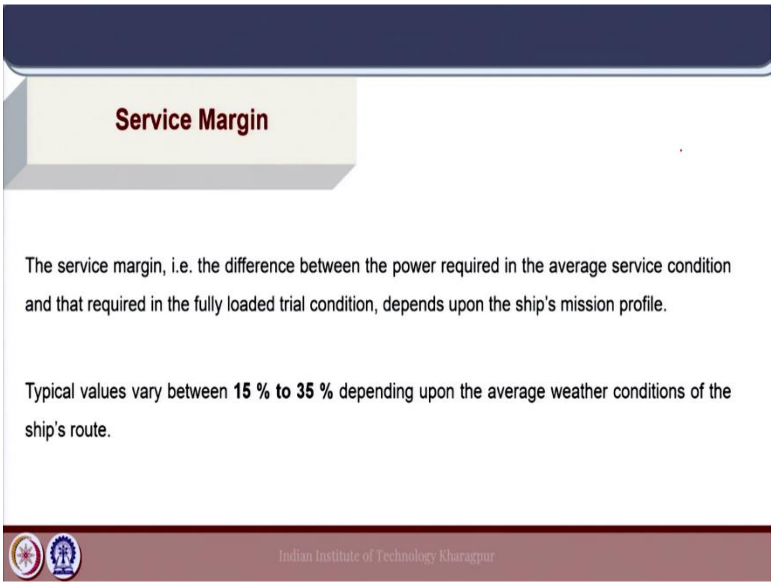

Now, the service margin which is the difference between the power demand between the fully loaded trial condition and the average service condition will depend on the operational characteristics of the specific ship type. Now, this can have a value of anything between 15 to 35 percent depending on the average weather condition on the ships route.

For ships which operate in very rough seas, where a greater speed loss is expected because of wave conditions, there the service margin has to be provided in a higher value. For ships which operate in weather conditions which are comparatively calm, a lower service margin can be provided. Also, other factors like docking intervals can also play a role in the service margin provided for a particular ship.

So, these margins engine margin and service margins are essential in estimating the powering performance with respect to the matching between the engine and the propeller curves for different operation conditions. Now, we will try to understand this concept of engine propeller matching with a very simple example.

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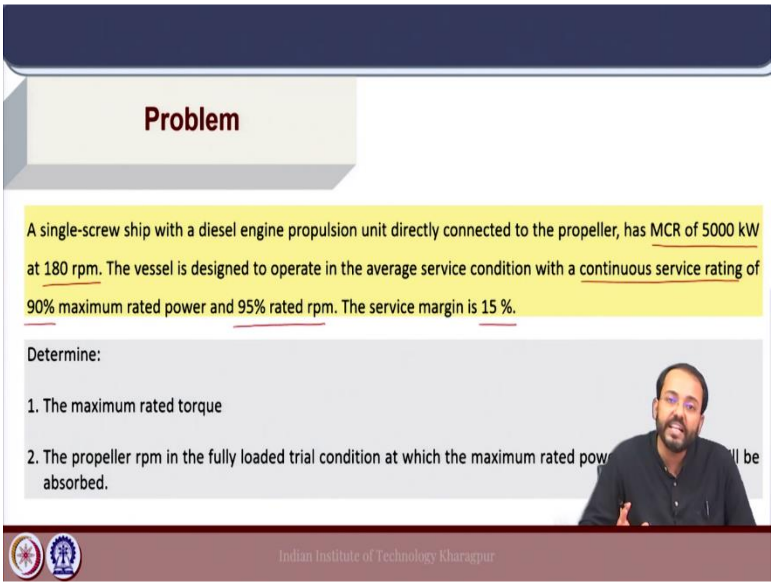

Now, let us consider a simple problem of a single-screw ship with a diesel engine propulsion. The engine being directly connected to the propeller, the maximum continuous rating of the engine is given and the rpm is given for the engine; the maximum values and the vessel is designed to operate in an average service condition with a continuous service rating, CSR of 90 percent of the maximum rated power and 95 percent of the rated rpm. The service margin is also given.

So, in this particular problem, the engine characteristics are given and the maximum continuous rating and continuous service rating are given along with the service margin. And we have to calculate the maximum rated torque and the propeller rpm for the fully loaded trial condition, where the maximum rated power of the engine will be absorbed ok.

So, based on the given data, we have to first calculate the maximum rated torque, which is very simple can be calculated from the maximum continuous rating and rpm for the engine and the next condition for the fully loaded trial condition, we are asked to calculate the propeller rpm, where the maximum rated power of the engine will be absorbed.

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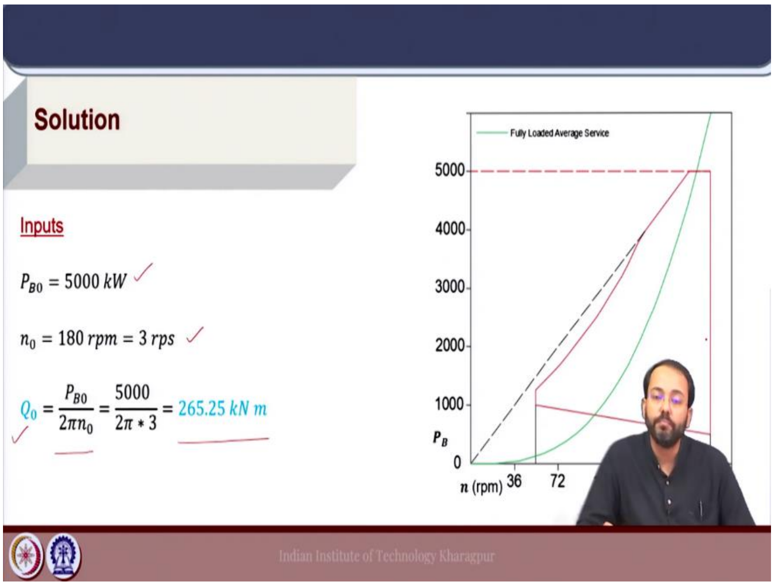

So, let us look into the inputs. The maximum rated power is given 5000 kilowatt the engine rpm 180, which is 3 rps. So, from these, we can calculate the torque, which is the first part of the answer from the engine brake power and the rpm, we can use this equation to calculate the torque ok. This is the diagram given for this particular problem, the engine curve and the propeller curve for the fully loaded average service that we will see now.

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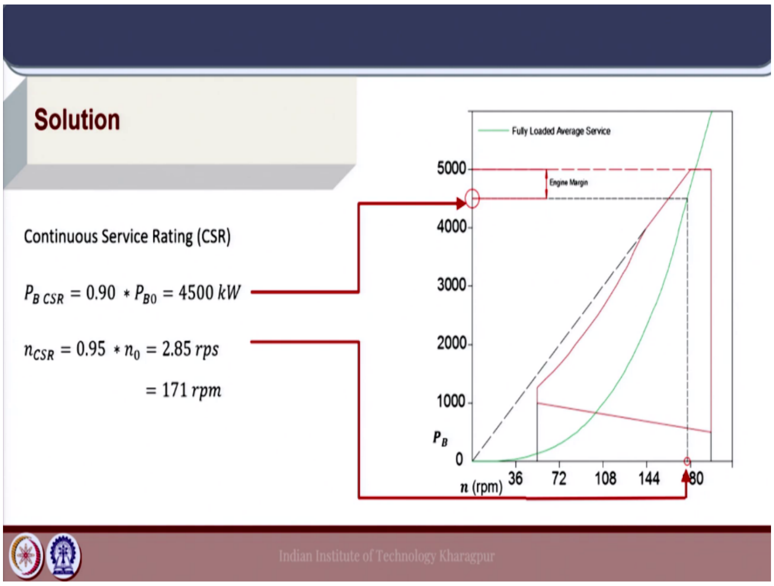

Now, the continuous service rating is 90 percent of the maximum power and here, we can see that the fully loaded average service condition can be intersected with the engine diagram and we can see that the point for continuous service rating can be obtained here. And the rpm at continuous service rating as per the given problem is 95 percent of the maximum rated rpm, which is 171 as shown here ok.

So, these two points are shown in the engine propeller matching and as per definition of continuous service rating, we have the fully loaded average service condition for the propeller shown here ok. So, this particular difference between the maximum continuous rating and the continuous service rating will be the engine margin in this problem.

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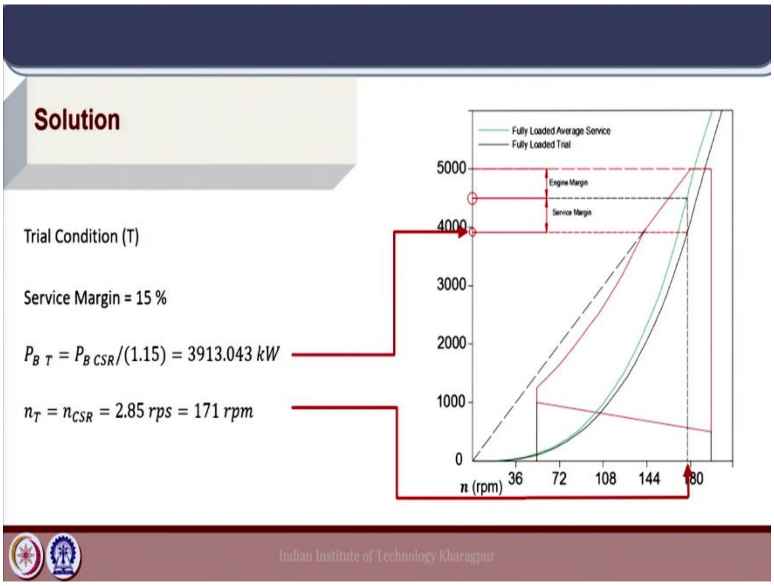

Now, for the trial condition, the next curve for the propeller is shown, which is the fully loaded trial curve for the propeller. Here what is given? The service margin is given 15 percent. Now, we have to remember here that the service margin of 15 percent is given over the power demand in the fully loaded trial condition. So, the power in the fully loaded trial condition can be obtained by the power at continuous service road rating divided by 1.15. Because this 15 percent margin is over the power in the fully loaded trial condition.

So, we know the case for the continuous service rating. We want to find out this point and we know that a margin of 15 percent is given on the trial condition. So, we can calculate P_{BT} in this manner and the rpm in the trial condition is the same as the continuous service rating as per the given value.

So, these are the two values of power and rpm that we have computed ok. This is the service margin; the difference between the green and the black lines; that means the difference between the power demand in the fully loaded average service condition and the fully loaded trial condition.

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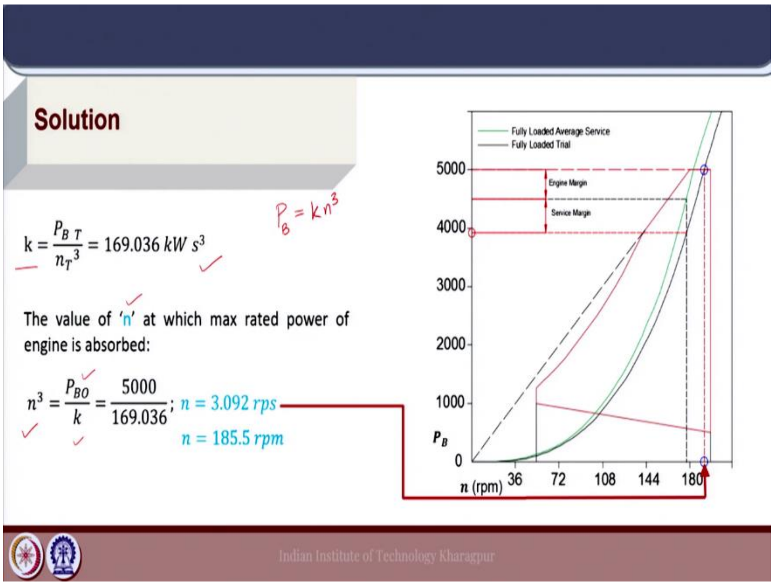

Now, for the propeller, we know that the assumption for the propeller power demand proportional to the cube of propeller rpm is used for engine propeller matching. So, we have to find that factor k, where $P_B = k\ n^3$ ok. We have calculated the P_B in the trial condition, P_{BT} and the rpm in the trial condition is also known. So, from that, we can calculate k. It will have units based on P_{BT} and n.

This k, now can be used to compute the second part of the question, where we need to calculate the rpm at which the maximum rated power of the engine will be absorbed? So, first, we are calculating the proportionality constant k and then, based on the given requirement, we are required to calculate the rpm at which the maximum rated power of the engine will be absorbed.

So, if n is that rpm, the maximum rated power given is 5000 kilowatt and we know the value of k. So, we can use this equation to get the value of n which is 185.5 rpm. So, we can calculate the value of the propeller rpm at which the maximum rated power of the engine is absorbed as per the details given in this problem.

So, this is how we can use the concepts of engine margin and service margin in engine propeller matching to solve for the rpm and power for different operation conditions of the ship. So, in general, engine margins and service margins are used to relate the propeller performance curves to the engine performance curve for specific operation conditions.

This problem will give a brief idea of how this can be used for ship powering. In combination with propeller design that we will study later; this will give a broad overview of the powering calculations and engine propeller matching involved for marine propulsion.

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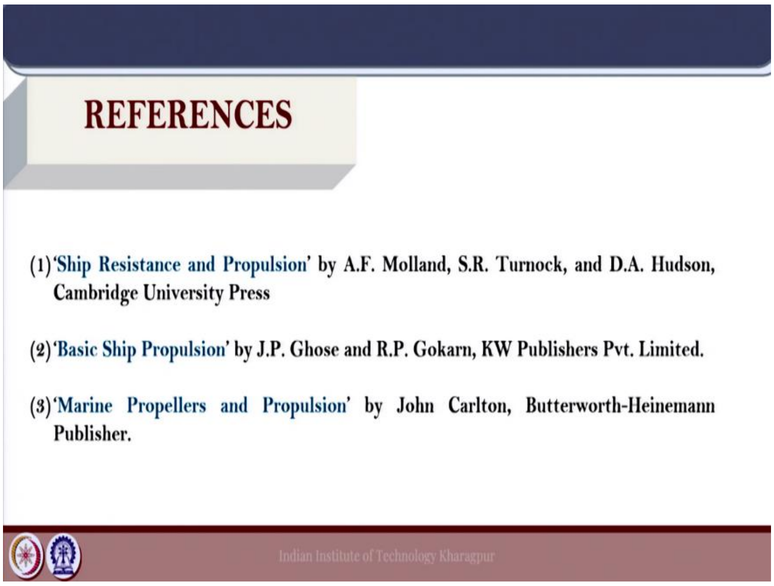

So, some references which can be looked into for ship powering in general and engine propeller matching are given here. This completes our discussion for hull propeller interaction and engine propeller matching.

Thank you.