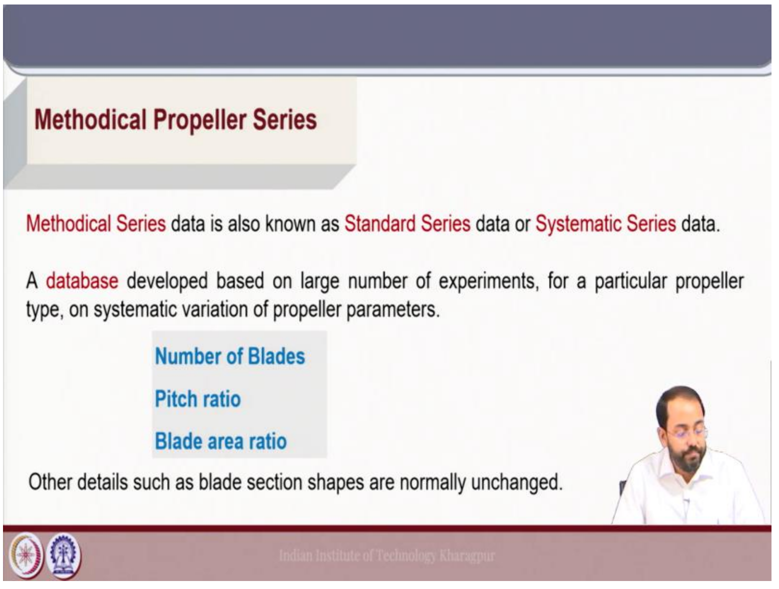
Marine Propulsion
Prof. Anirban Bhattacharyya
Department of Ocean Engineering and Naval Architecture
Indian Institute of Technology, Kharagpur

Lecture - 15
Methodical Propeller Series

Welcome to the 15th Lecture of the course Marine Propulsion, today we will be discussing Methodical Propeller Series.

(Refer Slide Time: 00:34)



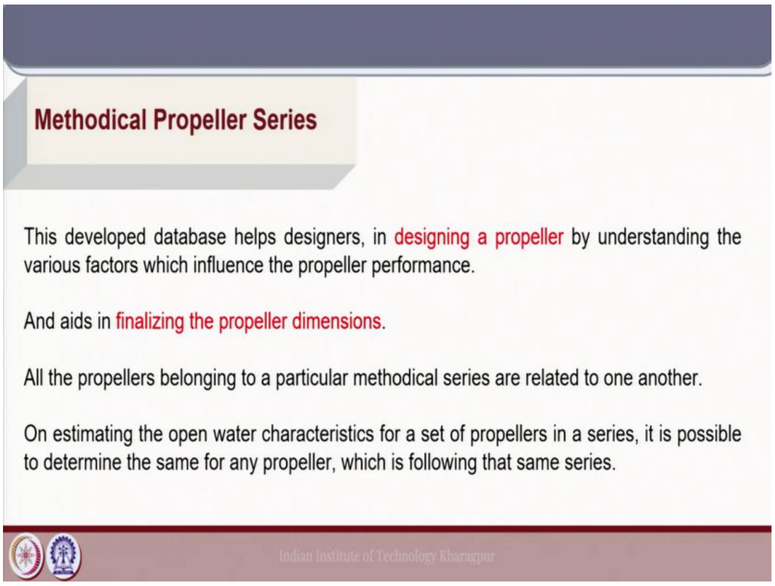
Methodical series data are used for different performance assessment of Marine Propellers. So, these are also called standard series or systematic series data which are developed based on experimentation on a number of propellers of varying characteristics.

So, if we have a particular propeller type and then by varying the parameters in a systematic way a series can be developed and that has been done over a wide range of parameters to have a basic data set which can be used for design of propellers. So, in terms of parameters the primary parameters which are varied to obtain these data sets are the numbers of blades pitch ratio and blade area ratio, which are very important in defining the propeller geometry.

And there are other details for example, shapes of blade section and other aspects like thickness ratio which are normally unchanged. So, keeping these parameters unchanged the parameters like number of blades, pitch ratio, blade area ratio are changed in a systematic way and then for a particular design experimentation is done and based on those obtained open water characteristics the methodical series is defined.

And these methodical series data are widely used in obtaining propeller design for specific conditions. So, if we have a requirement sometimes for preliminary design it is also very useful to have a first-hand idea of what the design should be. So, these data can be interpolated to get the results or the final design for a specific configuration between the values which are experimented for all these parameters.

(Refer Slide Time: 02:46)



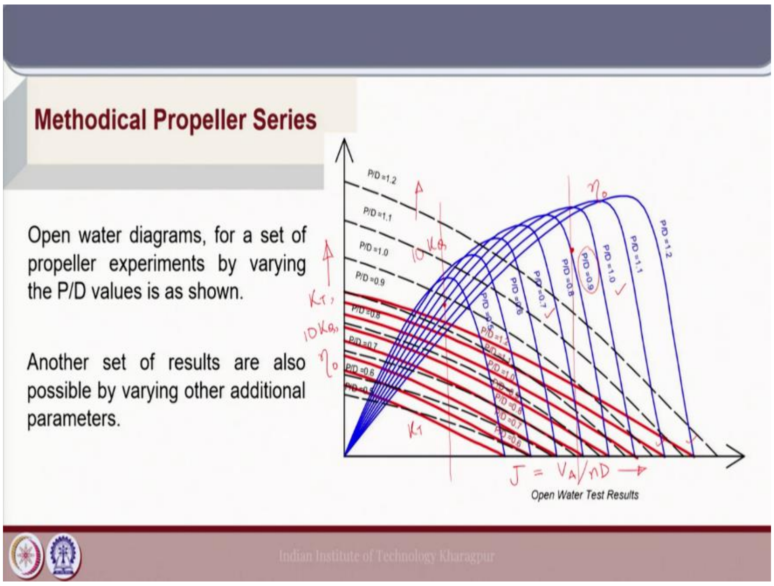
So, if we think of the database for designing a propeller certain factors are important and having a methodical series data gives a first-hand estimate to finalize the propeller dimension. So, when we discuss propeller design later in this course we will see that there are different parameters which impact the performance of a propeller.

So, the geometric parameters which impact propeller design vary from pitch ratio to blade area ratio, cambered, thickness, blade section and number of blades. In a typical methodical series some selected parameters are varied and this helps in making the design process easier.

So, if we think of a particular methodical series all the propellers belonging to that series are somewhat related to each other by these series of parameters, because certain aspects are constant in terms of the geometry of the propeller blade and when we have the open water characteristic for a set of propellers in the series.

So, if we have the limits defined by a specific series, we can obtain the characteristics of any propeller within the boundaries of those limits for the specified parameters, which we will try to understand when we go into each of these series.

(Refer Slide Time: 04:18)



So, this is a typical example of open water test results which are obtained by varying the P/D ratio. So, if we have a particular propeller geometry and the number of blades a/a_0 the blade area ratio constant, then just by varying the pitch ratio of the propeller blade we can obtain a set of curves.

Now, if we remember the x axis in the open water diagram is J, which is the advance coefficient V_A/ nD and the y axis has K_T, 10 K_Q and the open water efficiency. So, in these diagrams we have the K_T curves 10 K_Q curves and the η_o or the open water efficiency curves.

So, now if we see here by varying the pitch systematically the diagram changes, so this concept I will explain in more details when we talk about controllable pitch propellers. But the basic idea here should be understood that if we increase the pitch of the propeller blade here represented by the pitch ratio.

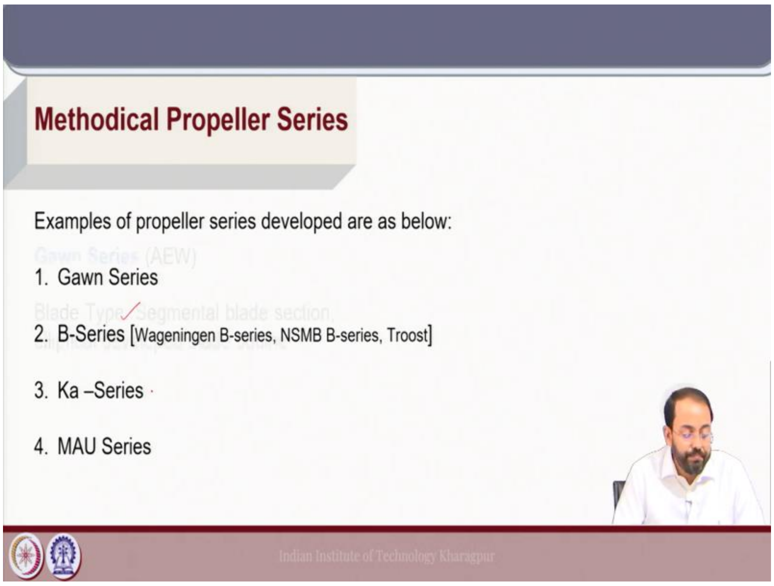
So, if we go from a value of let us say 0.7 to a high value of 1 with P by D ratio. What is the effect on the K_T, K_Q, and η_o? First by increasing the pitch ratio the angle of attack of the blade section increases. If we think of the blade element diagram the phase pitch angle defined by ϕ is a function of the P/ D ratio.

Now as we increase the pitch the angle of attack for the blade section will increase and the thrust and torque value will also increase. So, as we increase the pitch the K_T and K_Q values are increasing in that way the efficiency also has a wider range, because the K_T, K_Q curves go to 0 at higher values of J here as the pitch is increased.

So, the open water efficiency the entire operation range increases, but the efficiency is not always higher if we increase the pitch. So for example, if we look at a point here and take a point here ok. So, the efficiency for P/ D = 0.9 is this the same here will be lower compared to a case where P/ D = 0.5 or 0.6.

So, the efficiency range or the operation range increases as we increase the pitch. So, we can say that by varying the pitch ratio a systematic series of open water diagrams can be constructed for specific propeller geometry.

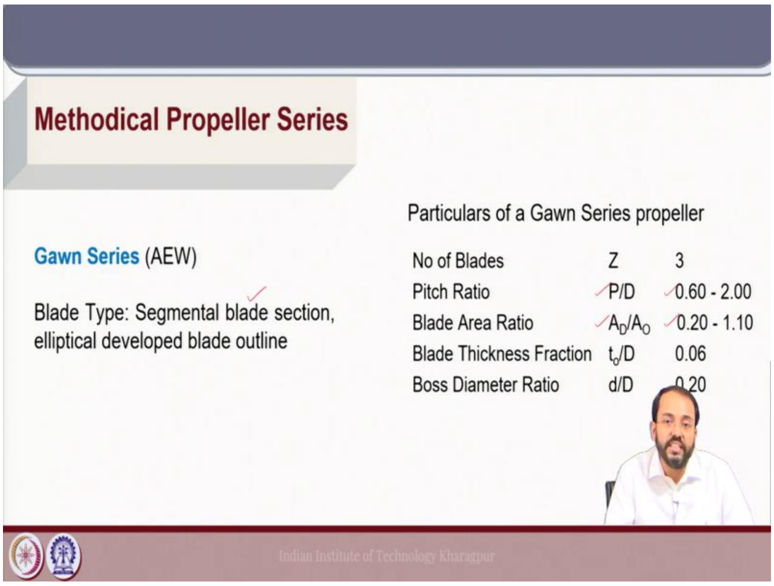
(Refer Slide Time: 08:11)



So, based on this concept certain propeller series have been developed. For example, Gawn Series the B-series or the Wageningen B-series developed at marine in Netherlands also called the Troost series sometimes, it is one of the most widely used propeller series for different purposes.

Ka-series it is the Kaplan Series also developed in marine and specifically used for ducted propellers, these aspects of Ka-series with ducts we will study under ducted propeller and MAU series is a propeller series developed in Japan.

(Refer Slide Time: 09:00)

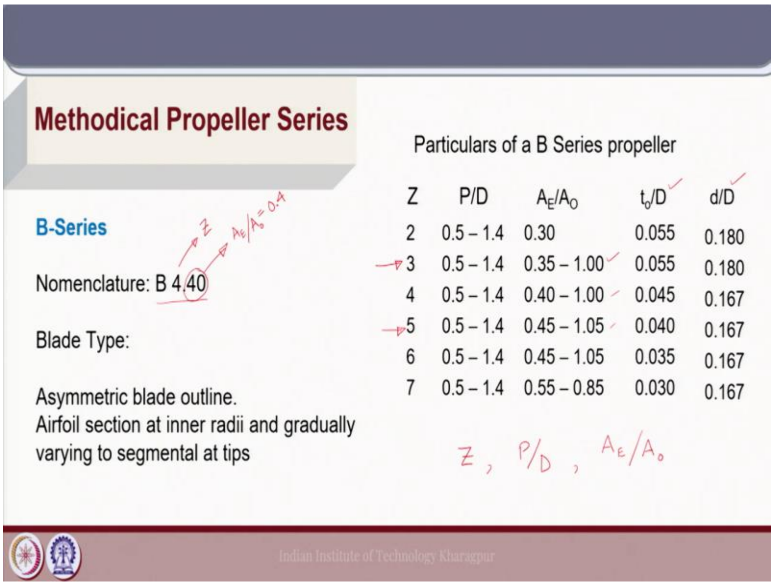


So, we will briefly look into Gawn series and B-series in terms of Methodical Propeller Series here. So, for the Gawn series the blade type is segmental blade section. So, the blade sections which are used are segmental in nature which we have discussed in propeller geometry and the developed blade outline is elliptical.

So, as every series I have mentioned has certain variables which are varied, so certain parameters which are varied and certain parameters which are kept constant which are specific for that series. So, here we will see in the Gawn series the variation is on the pitch ratio P/D which varies from 0.6 to 2 and the blade area ratio which is defined by the developed blade area in this particular series divided by the disc area is varying between 0.2 and 1.1.

So, based on these a range of open water diagrams are constructed which can be used for analysing and designing propellers under this particular series.

(Refer Slide Time: 10:21)



Now, for B-series a typical nomenclature is like this B 4.40, where 4 the first digit corresponds to the number of blades Z and the second one 40 divided by 100 that gives the A_E / A_0 the expanded blade area ratio that will be 0.4 ok. This is how B-series propeller nomenclature is done.

So, here the blade type is asymmetric blade outline and air foil section is used at the inner radii and gradually varying into segmental sections at the tip. Now because at the tip there are higher chances of cavitation that is why segmental sections are used which has certain pressure characteristics which is more conducive towards the tips; that is why for B-series propeller a combination of air foil and segmental sections are used.

Now, B-series propellers have a huge database varying from blade numbers 2 to 7 blades and for each case different P /D ratios are investigated. So, these series are developed based on experimental results on model propellers over these ranges of parameters and in during design which we will discuss later under propeller design, we can use these data to get our specific design based on the input requirement by suitable interpolation using certain constants which are essential for the design process

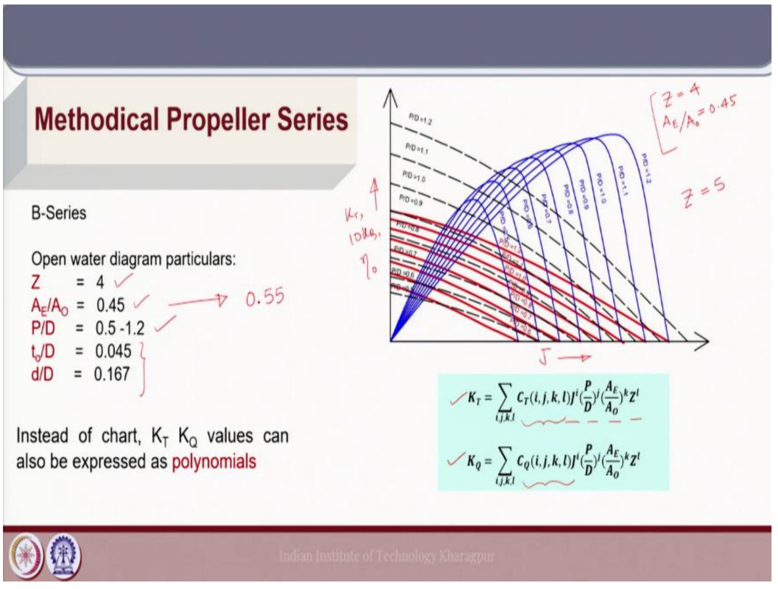
Now, A_E/A_0 here the expanded blade area ratio is used in denoting the B-series propeller area and for these different kinds of blade numbers the A_E/A_0 ranges are shown for each case. Let us take 2 cases for number of blades 3 and number of blades 5. So, we will see that as the number of blades increases the naturally there will be an increase in the blade area, because the disc area A_0 is defined by the diameter A_0 is nothing but π $D^2/4$, where D is the diameter of the propeller.

So, if we increase the number of blades within the same area, if we try to put more number of blades what will happen the basic A_E/A_0 will increase, that is what is shown here? As the number of blades increases the A_E/A_0 range is different.

Now, t/ D is the thickness ratio which is kept constant for a specific case which belongs to a specific number of blades. So, for each case you will see t_0/ D and d/ D is the ratio of the boss diameter to the propeller diameter.

So, these ratios are kept constant. So, the only things which are varied are Z, P/D and A_E/A_0 and this chart is shown as variations of P/D and A_E/A_0 for a specific Z. So, if we combine this entire data set it gives a wide range of variations of these 3 parameters which forms a database based on which propeller characteristics in open water are presented and which can be used for design.

(Refer Slide Time: 14:44)



So, again just like the one that we have seen variation of pitch let us take a B-series example we have a propeller with 4 blades A_E/A_0 of 0.45 and we try to see it is open water characteristics for a range of pitch ratio P/ D of varying between 0.5 and 1.2 and these factors t/ D and d/D are constants as mentioned.

So, if we look at the open water diagram as before we have $K_{T,}$ 10 $K_{Q,}$ and η_o as functions of J the advance coefficient and as the pitch ratio increases the K_T and K_Q in the open water diagram will increase, that we have discussed just now. And similarly the open water efficiency values will reflect these changes in K_T and K_Q for different pitch ratios.

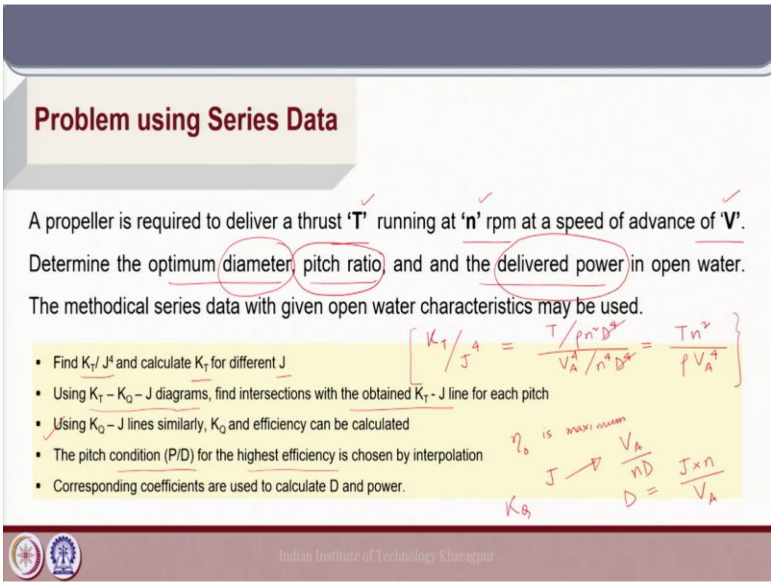
So, now if we take another value of A_E/A_0, if we go back let us say we take a value of 0.5 which is between these values. So, if we take another value here of 0.55 then we will get a new series of $K_{T,}$ $K_{Q,}$ and η_o versus J. So, a new set of open water curves will be generated in the same range of P/ D. So, this particular diagram is valid for A_E/A_0 equal to 0.45 and Z equal to 4.

So, if we go from this to any other basic constants. For example, if we take Z equal to 5 or Z equal to 6 or keep the J constant and change the A_E/A_0 value, then this entire diagram will be changed and that will again create a new set of curves which will be part of the larger data set.

So, instead of these curves polynomials can also be used to represent the values of K_T and K_Q in the open water condition for a range of values of pitch ratios blade area ratio and number of blades. So, they are represented using these equations where K_T is expressed as functions of J, P/D, A_E/A_0 and Z. And these coefficients C_T and similarly for K_Q we have C_Q will depend on these four parameters.

So, for a specific set these coefficients are calculated based on regression analysis of all the experimental data for K_T and K_Q for this change of parameters for specific designs. So, these B-series open water diagrams can be represented using these polynomial expressions for K_T and K_Q which can be used in propeller design.

(Refer Slide Time: 18:44)



Now, if we look at a simple problem which can be done using B-series or any methodical series data. So, for this we have been asked to determine some parameters for a propeller for which the thrust rpm and velocity of advance is given. So, the requirement of thrust to be delivered at a particular rpm for a particular speed of advance is given and we have to determine the optimum diameter pitch ratio and the delivered power in the open water condition.

So, this is not a proper propeller design problem, this is just an example to use the open water charts K_T, K_Q charts simply to arrive at a particular optimum design for specific requirements. So, what we can do here is the thrust rpm and advanced velocity is given.

So, if we think of these factors K_T has a term propeller diameter in it and J also has propeller diameter in it. So, if we take K_T/ J^4 it gives $T/ (\rho\, n^2\, J^4\, V_A^4)$ right.

So, here what is simply done is the diameter is eliminated because, it is an unknown that we have to find in this problem. So, this gives $T\, n^2/ (\rho\, V_A^4)$. So, from the given data we can calculate this expression, because the thrust the rotational speed and the velocity of advance is given. So, if we do that we can use this to calculate K_T for different J values.

Now, we can use the series data here it is implied in this problem that the series data for a range of pitch ratios are available ok. So, this is just a sample problem which I am using to explain how we can use series data to arrive at a simple design using the open water diagrams.

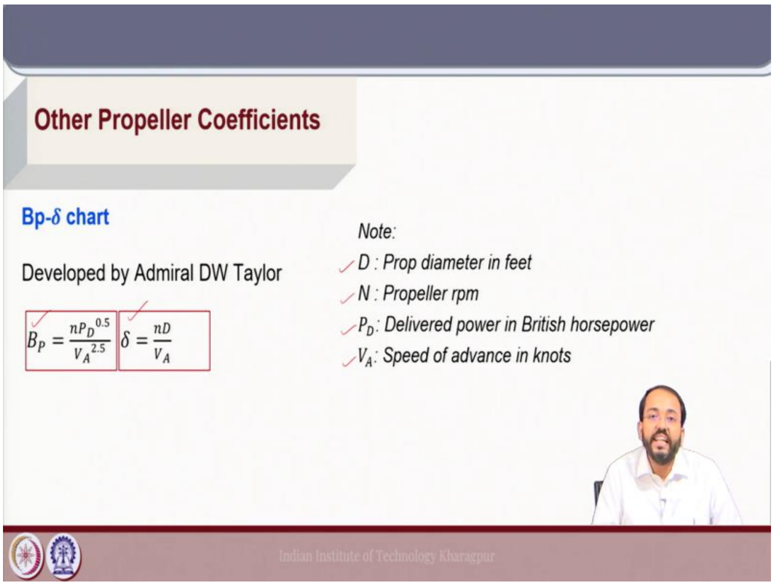
So, from these K_T, K_Q, J diagrams or polynomials we can find the intersections with this K_T versus J line for each pitch that we have defined for a specific K_T/J^4. Now using similar lines for K_Q versus J the K_Q as well as open water efficiency η_o can also be calculated, because we already have the open water diagrams for the propeller series.

Now, we have to choose the pitch condition for the given case, where we have the highest efficiency. Now these K_T/J^4 this intersection with the K_T, K_Q, J diagrams will correspond to a particular point for every P/ D. Now technically we can choose any of these points as a suitable design, but normally in propeller design we will try to go for the option where the open water efficiency is highest, if there are no other constraints here we are not given any other constraints.

So, we will choose the pitch condition for which η_o is maximum from these intersections. Now, once we choose that, so we already have calculated the optimum pitch ratio for which η_o is maximum, then we only have to calculate the optimum diameter and delivered power. Now for that corresponding condition if we calculate J then using that J we can calculate J is V_A/ nD. So, the diameter is J × n / V_A.

So, the optimum diameter can be calculated next and finally the delivered power can be calculated using the K_Q value or the torque coefficient for that specific J ok. So, we choose the P/D ratio based on the maximum efficiency from the given set of curves and from that we get the value of J and finally, calculate the power using the torque coefficient.

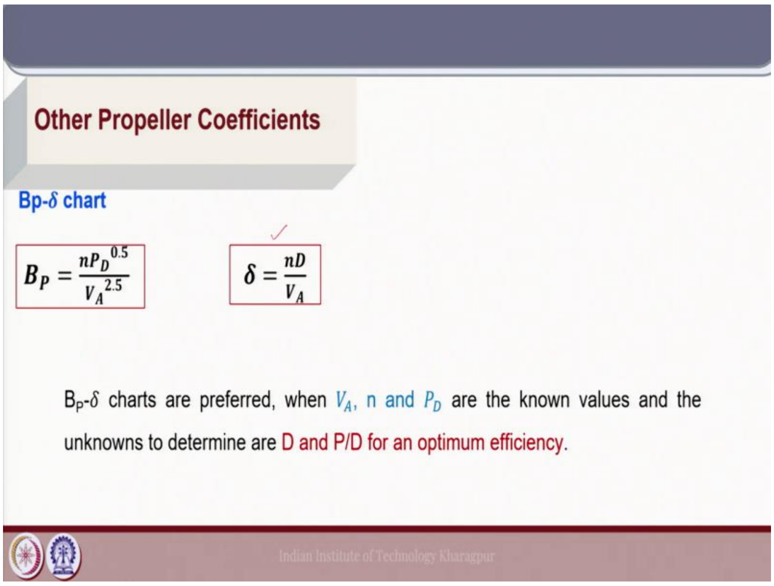
(Refer Slide Time: 24:47)



Now, we move on to some other charts or propeller coefficients which are used extensively for propeller design. One such example is the Bp-δ chart developed by Admiral Taylor where the coefficients Bp and δ are given in relation to the propeller rpm, diameter, the delivered power and the advance speed.

Here the system which is used is the British system. So, P_D is the delivered power in British horsepower and V_A is the advanced speed in knots. Whereas, you have the propeller diameter in feet and n is propeller rpm. So, for a specific problem when we use these charts we have to convert the case that we are designing into these units and then the Bp-δ chart can be used.

(Refer Slide Time: 25:50)

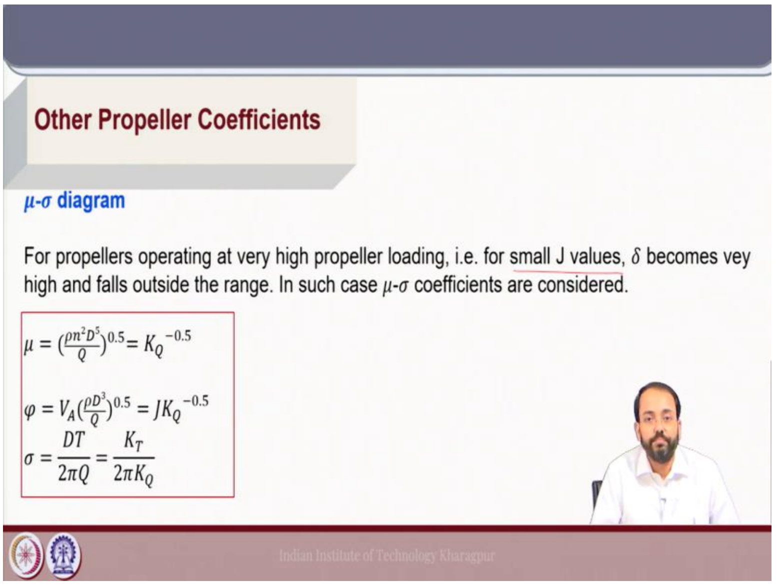


So, in the Bp-δ chart we have the Bp and δ as functions of these parameters for the propeller. So, in this particular equation delta is nothing but the inverse of J expressed as n D divided by velocity of advance.

So, these charts are preferred when the advance velocity rpm and delivered power are known and we have to design the propeller in such a way that the diameter and P/ D or the pitch ratio are unknown. And these will be the outcome of the design and we have to look for the case with optimum efficiency.

So, when we do B-series propeller design under the propeller design part of the course then I will show these charts and explain the concept of optimum efficiency and how it can be used in propeller design.

(Refer Slide Time: 26:51)



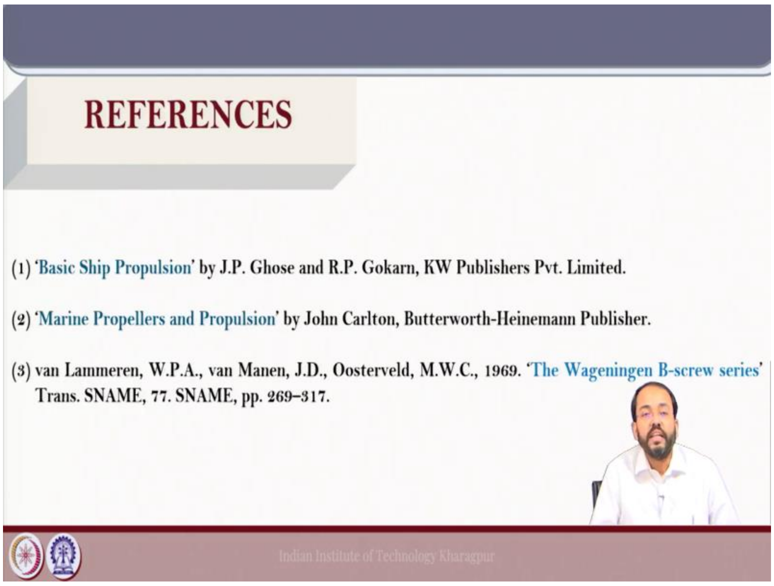
Another diagram which is used for propellers operating at very high loading is the μ-σ diagram. So, very high loading means we have very small J values, because the propeller loading is high when the J value is low; that means, the K_T and K_Q is very high. So, the thrust loading is high.

So, in these conditions delta becomes very high ok, because in the Bp-δ diagram δ is basically the inverse of J. So obviously, for very high loading the delta value will be high and will fall outside the range of the standard Bp-δ diagram.

So, for those cases μ-σ diagram are used and these coefficients are also used for propeller design for vessels, where the propeller loading is very high. So, the coefficients which are used in this particular diagram are given here as functions of K_T K_Q and J, the advance coefficient and the thrust and torque coefficients in open water. So, these coefficients are used in designing propellers with high propeller loading using this μ-σ diagram.

So, this will be all for the methodical series part and this ends our discussions on propeller in open water, we will continue with propeller behind hull in the next class.

(Refer Slide Time: 28:23)



Some references which can be used in general for propeller in open water and also for the B-series propeller are given here.

Thank you.