Exercise

Ship Design

Propulsion and Power-Calculation of RoRo Ship

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Exercise 4

You are provided the following information about a 3200 lm RoRo vessel.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(L_{OA})</td>
<td>[m]</td>
<td>199.80</td>
</tr>
<tr>
<td>(B)</td>
<td>[m]</td>
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<tr>
<td>(T_D)</td>
<td>[m]</td>
<td>7.40</td>
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<tr>
<td>(\eta_{kgs})</td>
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<tr>
<td>(P_{\text{electric,seamode}})</td>
<td>[kW]</td>
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</tr>
<tr>
<td>(P_{\text{electric,harbour}})</td>
<td>[kW]</td>
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<tr>
<td>(EM)</td>
<td>[%]</td>
<td>10</td>
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<tr>
<td>(R_T(v_s = v_{\text{Design}}))</td>
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<tr>
<td>(\eta_R)</td>
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</tr>
<tr>
<td>(w)</td>
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<tr>
<td>(t)</td>
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<td>(D_{\text{Prop}})</td>
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<tr>
<td>(v_{\text{Design}})</td>
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<tr>
<td>(v_{\text{Off-Design}}\text{1})</td>
<td>[kn]</td>
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<tr>
<td>(v_{\text{Off-Design}}\text{2})</td>
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<td><strong>Main Engine</strong></td>
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<tr>
<td>(P_{\text{Cyl}})</td>
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<tr>
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<td>(\Delta \text{SFOC}_{\text{coolingwaterpump}})</td>
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<td>(\Delta \text{SFOC}_{\text{luboilpump}})</td>
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<tr>
<td>(\text{GenSet})</td>
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<tr>
<td>(\text{SFOC}_{\text{luboilpump}})</td>
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<td>1.01</td>
</tr>
<tr>
<td>(\Delta \text{SFOC}_{\text{tropicalcond.}})</td>
<td>[-]</td>
<td>3.0</td>
</tr>
<tr>
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<td>[-]</td>
<td>1.05</td>
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</table>

1. Calculate the self propulsion point for the design speed.

2. Compare the given engines and develop machinery concepts for the power supply.

3. Now compare the general concept for the propulsion and energy supply. Choose one engine type and one concept. Please explain the reasons of your decision.
1. Calculate the self propulsion point for the design speed.

For calculating the propulsion power the propulsion efficiency has to be determined. In order to do so we have to calculate the selfpropulsion point of the propeller, to get the missing open water efficiency of the propeller.

\[
k_T^* = \frac{k_T}{J^2} \cdot J^2
\]  

(1)
with:

\[ k_T = \frac{T}{\rho D^4 n^2} \]  
\[ J = \frac{v_a}{nD} \]  
\[ T = R_T \cdot \frac{1}{(1 - t)} \]  
\[ v_a = v_s \cdot (1 - w) \]  

From the resistance curve we have:

\[ R_t(v_a = 21.5\text{kn}) = 882.0\text{kN} \]  

Because the overall thrust is generated by two propellers, the thrust in equation 2 has to be multiplied with 1/2, in order to calculate the thrust of a single propeller. \(k_T^*\) calculates to:

\[ k_T^* = \frac{T \cdot 0.5}{\rho D^4 n^2} \cdot \frac{nD^2}{v_a^2} \cdot J^2 = \frac{R_T \cdot 0.5}{\rho D^2 (1 - t)} \cdot \frac{1}{v_s^2 \cdot (1 - w)^2} \cdot J^2 \]  
\[ = \frac{882 000 \cdot 0.5}{1.025 \frac{m^3}{h^3} \cdot (5.75\text{m})^2 \cdot (1 - 0.09) \cdot (21\text{kn} \cdot 0.5144 \frac{\text{kN}}{\text{s}})^2 \cdot (1 - 0.075)^2} \cdot J^2 \]  
\[ = 0.1366 \cdot J^2 \]  

By drawing the curve into the open water propeller diagram we find the crossing point (propulsion point) with the \(k_T\)-curve at \(J_e = 0.86\).

The open water efficiency at this point is: \(\eta_O = 0.7\)

2. Compare the given engines and develop machinery concepts for the power supply.

By looking at the two given engine loading diagrams one can see, that the curve of the MAN-engine is a lot broader and so will easier work with CPPs in combinator mode. The MaK-engine will basically work only with constant-rpm-mode CPPs at nominal rpm. As discussed in the exercise it is for propulsional and manoeuvring reasons better to drive CPPs in combinator mode.

At this point we will take a look on one engine-setup A with two main engines for propulsion and a PTO for providing the electric power in sea mode. On the other hand we will look at a setup B with two main engines for propulsion and an additional genset for providing the electric power. As also discussed in the exercise we have to take into account that we need to install a GenSet in any way for the harbour operation and that we also have to install an emergency genset.

3. Now compare the general concept for the propulsion and energy supply. Choose one engine type and one concept. Please explain the reasons of your decision.

The main aspect for the decision is often the fuel oil consumption at sea. For calculating the delivered power \(P_D\) at the propeller we first need to calculate the effective power.
\[ P_D = \frac{1}{\eta_D} \cdot P_E = \frac{1}{\eta_D \cdot \eta_H \cdot \eta_R} \cdot P_E \quad (10) \]

\[ P_E(v_s = 21.5\text{kn}) = R_t(v_s = 21.5\text{kn}) \cdot v_s = 882\text{kN} \cdot 21.5\text{kn} \cdot 0.5144 \cdot \frac{m}{s \cdot \text{kn}} = 9755\text{kW} \quad (11) \]

And next we have to calculate the hull efficiency:

\[ \eta_H = \frac{1}{1 - t} = 0.984 \quad (12) \]

The rotative efficiency is given and so the propulsion efficiency \( \eta_D \) is delivered power \( P_D \) calculates to:

\[ \eta_D = 0.7 \cdot 0.984 \cdot 0.99 = 0.682 \quad (13) \]

And the delivered power follows as:

\[ P_D = \frac{1}{0.682} \cdot 9755\text{kW} = 14304\text{kW} \quad (14) \]

From this point on we have to look at the two typical setups A and B for the machinery. First we look at two main engines combined with a PTO:

Including the efficiency of the clutch, gear and shaft, the electric power and the engine margin we calculate the minimum demanded power at the engines’ flywheels as well as the corresponding installed maximum power.

\[ P_B = \frac{P_D + P_{el}}{\eta_{cgs}} = 15565\text{kW} \quad (15) \]

\[ P_{MCR} = \frac{P_B}{(1 - EM)} = \frac{15565\text{kW}}{(1 - 0.1)} = 17294\text{kW} \quad (16) \]

This yields the minimum number of cylinders:

\[ n_{cyl.} = \frac{P_{MCR}}{P_{cyl.}} = 14.4 \quad (17) \]

So we have to choose two engines with eight cylinders each.

The time specific fuel oil consumption can be calculated like this:

\[ \dot{m} = (P_B) \cdot (SFOC_{90\% MCR} \cdot f_{SFOC, tolerance, manufac.} + \Delta SFOC_{coolingwaterpump} + \Delta SFOC_{luboilpump} + \Delta SFOC_{tropicalcond.}) \cdot f_{SFOC, tolerance, HFO} \quad (18) \]

\[ = 15565\text{kW} \cdot 201.6 \cdot \frac{g}{\text{kWh}} = 3.138 \cdot \frac{t}{h} \quad (19) \]
At this point we neglect the changing of the nominal specific fuel oil consumption with the engine’s operating point. This is just done for time saving reasons in the exercise. In fact the nominal SFOC should be altered in accordance with the operating point.

For the second setup B we choose two main engines for propulsion and the electric power will be provided by a genset.

\[
P_B = \frac{P_D}{\eta_{cgs}} = 14596\text{kW}
\]  
\[
P_{MCR} = \frac{P_B}{(1 - EM)} = \frac{14596\text{kW}}{1 - 0.1} = 16218\text{kW}
\]

This yields the minimum number of cylinders:

\[
n_{cyl.} = \frac{P_{MCR,\text{min}}}{P_{cyl.}} = 13.5
\]

For providing the electric power the following installed generator power is required:

\[
P_{MCR,\text{Gen}} = \frac{P_{el.}}{(1 - EM)} = \frac{950\text{kW}}{1 - 0.1} = 1055\text{kW}
\]

Therefore we choose two main engines with seven cylinders each and for providing the electric power in sea mode a single genset.

The time specific fuel oil consumption in this case can be calculated as follows:

\[
\dot{m} = P_B \cdot (SFOC_{90\%MCR} \cdot f_{SFOC,tolerance,manufac.} + \Delta SFOC_{\text{coolingwaterpump}} \cdot f_{SFOC,tolerance,HFO}) + \Delta SFOC_{\text{luboilpump}} + \Delta SFOC_{\text{tropicalcond.}} \cdot f_{SFOC,coolingwaterpump} + P_{el.} \cdot (SFOC_{90\%MCR} \cdot f_{SFOC,tolerance,manufac.} \cdot f_{SFOC,coolingwaterpump} \cdot f_{SFOC,luboilpump} + \Delta SFOC_{\text{tropicalcond.}} \cdot f_{SFOC,tolerance,HFO})
\]

\[
= 14596\text{kW} \cdot 201.6 \cdot \frac{9}{\text{kWh}} + 950\text{kW} \cdot 213.5 \cdot \frac{9}{\text{kWh}} = 3.145\text{t/h}
\]

Obviously the difference in the fuel oil consumption is very small. This is caused by the relatively high SFOC of the propulsion engines and by the low electric power. Thus we have to find other reasons for making a decision.

Setup A yields higher investment costs because larger engines and the additional component of the PTO is required. Furthermore the PTO demands a constant rate of revolutions if no frequency converter is installed, so in that case the CPP can only be used in constant-rpm-mode. If a combinator mode is desired an additional very costly frequency converter is required. On the other hand the gensets can be switched off in sea mode which results in lower operating hours and maintenance costs. Hence the setup B is favourable in terms of investment costs and a flexible operation of the vessel.

As discussed in the exercise a combinator mode is only possible with the MAN-engine which is chosen in setup B.