PODDED PROPULSION

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1.0 BACKGROUND

Podded propulsion is an advanced ship concept which represents a radical departure from the traditional design philosophy of propulsion systems. In conventional arrangements each propeller is mounted on the aft end of the shaft supported by the struts and the ship is steered by rudders. For the podded propulsion the propeller is fitted at the fore end of azimuting pod (That can rotate by 360 deg) located just in front of the ship stern with the electrical engine located inside the shell of the pod gondola .The use of mechanical azimuting pod system with the engine connected to propeller through shafts and mechanical coupling has been widely used in the past , especially for the outstanding manoeuvring quality of the system , but the use was limited to small vessel due to limitation for the installed power .

The location of the electric engine directly inside the pod shall can solve the problem of delivered power , making the new system attractive for big cruise vessels and ferries provided with diesel electric propulsion. The problem of the new device was connected to safety as the engines fitted in the submerged pod are subject to damage and are not accessible for repairing. But since the beginning in the late eighties ,starting with the application on single screw supply vessels ,artic tankers and icebreakers, the system proved to be efficient and reliable.

The success followed in the nineties with the application on many twin screw passenger cruise vessels proving the high reliability of the electrical pod system , with better hydrodynamic performance regarding propulsion efficiency, manoeuvring ,vibration and propeller cavitation compared to the previous conventional ships. It has to be noted that the podded propulsion looks more attractive especially for diesel electric twin screw vessels fitted with pulling propellers .This presentation will consider just this arrangement. The better propulsive improvements in fact are related to the improvements and simplifications of the hull geometry as rudders , shaft lines , brackets , and other appendages and discontinuities can be removed and substituted by pods with consequently less resistance and flow turbulence.

In addition the pulling propeller rotates in an undisturbed flow without wake peaks and the shadow of the appendages providing an optimum cavitation behaviour with small pressure fluctuations, giving low hydrodynamic loads and reduced vibrations. It has been shown that an electric pod propelled twin screw vessel can combine ,in addition to the good well known harbour and at sea manoeuvring performance ,a better hydrodynamic performance and higher confort standart on board . Fitting of pods drive can have significant impact on the aft ship arrangements and influence on the hydrodynamic design of the stern of the vessel , as new and innovative different hull shapes can be used improving the propulsion performance of the of the ships and reducing production costs. Therefore complete new stern forms have been studied for new podded ships prototypes ,and in the case of sister ship repetition , where production needs require to keep limited the amount of changes. unless extended but suitable aft hull modification has been investigated.Tank testing investigations have been used for the optimisation of these new configurations of hull and propeller geometry to get the best hydrodynamic performances providing new design guidelines for podded twin screw vessels.

2.0 GUIDELINES FOR HULL DESIGN

Three different cases of pod fitting are taken into account.

2.1 fitting to an existing hull geometry.
2.2 small hull modification in way of the stern
2.3 complete redesign of stern geometry

2.1

In the design of twin screw vessel , it is a common use to adopt stern frame geometries with tunnel or wing type shapes in order to increase tip clearance and consequently to reduce the propeller induced loads and consequently vibrations. This implies production complications and a longer time for steel plate and frames definition cutting and assembly. The shortest way to fit the pod drive on an existing hull with tunnel shape consist in the removal of rudder and shaft lines and stern thrusters and connecting the pod to the hull through an inserted head box. In this case speed improvements are mainly related to the removal of appendages even if the hull shape seems to be not the most suitable for the pod fitting , but it represent the most economic way to fit a new pod drive to an existing ship design. Production needs can require to keep the rudder axis in the same position both transversally and longitudinally in order to have the lower impact on ship arrangements and on hull geometry, however it seems that a relocation in a most proper longitudinal and transversal position can lead to better hydrodynamic performance. Also the inserted head box for the pod feet is connected to the hull with sharp knuckles and this creates additional hydrodynamic losses.

2.2

Dealing with the modification of an existing ship , with both targets to improve hydrodynamic efficiency and keeping the amount of modification on general arrangements and steel manufacture as little as possible ,it could be a good compromise to limit the stern modification till at a certain frame and to redesign the geometry of this new part and to select the new pod position in the most proper way. In this case even if a faired skeg can be kept , the sections could be thinner and more streamlined , the adoption a tunnel shape is no more required and a simpler pram type geometry can be used reducing consequently costs and production time. At the same time the most proper position and orientation of the pod can be selected but keeping in mind that scantling and waterlines length should not be changed .The connection to the hull can be made through a faired head box , and the hydrodynamic results adopting this solution can be far better compared to the mere pod fitting to an existing hull. The substitution of the conventional tunnel shape with of the pram frame geometry is allowed as the inflow to the propeller is strongly improved since the propeller is rotating in an undisturbed wake without the deep shadow of shafts and brackets, and moving the pod aft the tip clearance can be kept or even increased as well.

2.3

A further step is the complete redesign of the stern hull geometry studying a complete new ship. Keeping the same philosophy of using a pram type shape further improvement could be achieved. The thin skeg can be directly inserted in the hull with small rounding connections and the longitudinal buttocks can be connected every gently to the bottom. For a conventional vessel the buttock inclination is limited and directly connected to the extension of the shaft line and the bossing geometry selected for a proper arrangement of the bearings.A well smoothed buttock line reduces the areas of low pressure in way of the connection to the bottom and consequently risks of separation and vorticity with a further improvement of the wake field in way of the propeller. The hydrodynamic investigation in the case a new ship can be concentrated in some very sensitive areas like the transom (selecting the most suitable immersion and

buttock inclination for the outflow and using in some cases the trim wedges) or the bilge connections between the bottom to the side of the frames (varying the value of the radius).
A good improvement can be also achieved selecting the most suitable longitudinal pod inclination and rudder angle. As a thumb rule half of the buttock inclination can be a good starting choice.

NOTE
Following actions can be applied in designing a new ship or modifying an existing vessel with pods drives. Selection of pram type geometries instead of more complicated tunnel shape. Use of well smoothed buttock lines avoiding sharp angles with bottom . Adoption of thin inserted skegs with small rounding radii. Relocation of pod as close as possible to the transom and transversally more outward. Connection of the pod to the hull through a well faired head box.

3.0 SEA TRIAL PREDICTIONS

Comparing tank tests results with existing ships and new podded hulls as a general tendency it seems that the simplified geometries can give improvements even comparing bare hull results. This improvements becomes more pronounced examining propulsion test even if some discussion are running concerning the most suitable test procedure and comparison way. It has to be considered that , for a reliable prediction of ship performances on true scale during sea trials, tank test results are normally corrected by means of statistical data obtained from previous similar vessel. For electric podded twin screw few feed back data exist as only few prototypes have been built till now , therefore there are still question regarding the most proper sea trail prediction method. One prediction method consists in using the ITTC 1957 formula of frictional resistance coefficient and a correlation allowance of Ca =0.00002 .

To arrive at the shaft power prediction the following allowance can be applied.PS-trial =1.03 * PD-tank These correlation allowances and scale effects corrections are based on statistical records on trail measurement for ship of comparable size and displacement. It must be noted that for ship equipped with pod drives some consideration have to be applied. Because the pod drives are relatively small compared to the length of the ship hull these elements suffers from low Reynolds numbers during model testing and thus are subject to scale effects.However the correction for these effects is made in this way. Both thrust delivered by propeller and the thrust delivered by complete units are measured separately by means of force transducers .The difference between the thrust of those two parts is considered to be the pod drive resistance on model scale.To account for the pod drive scale effect it is assumed that half the measured model pod drive resistance is scale effect. Therefore half of the resistance is subtracted from the towing force measured during the model propulsion , prior to extrapolation of the results.
When a ship is propelled by thrusters , the part of the scale effect correction for the conventional propulsion appendages incorporated in the trail allowance could be not applicable anymore and should therefore be taken out of the trail allowance which results into an increased trial allowance factor.
Therefore a suggestion would be to correct trial allowance according to following factor:
PS-trial =1.06 * PD-tank or even 1.08 Confirmation shall be possible after completion of a certain number of sea trails when feed back data shall be available.

4.0 PROPELLER DESIGN

For propeller design two opposite aspects have to be taken into account : efficiency on one side and cavitation and pressure pulses on the other . For a modern cruise vessel or passenger ferry with high confort levels the second factor holds and outstanding importance. In order to reduce the amount of cavitation and the pressure level it is necessary to act on following items.

4.1 Wake
4.2 Propeller design
4.3 Propeller hull clearance.

4.1 The wake

The wake on a twin screw vessel is mainly affected by two factors.

4.1.1 Hull form
4.1.2 Appendages.

4.1.1 Hull form

Stern hull forms are fundamental to create a good wake pattern. For a convention twin screw vessel in order to increase hull-propeller clearance it is common practice to design the stern frames adopting tunnel shape as a clever device to increase the tip clearance. In the design of a conventional tunnel twin screw vessel the stern buttocks lines design is strongly influenced by the need of fitting the bossings for the shaft lines and keeping a certain required hull- propeller clearance values. In the definition of the hull geometry particular care shall be given to the study of stern frame sections by means of CFD tools and tank testing. In fact high clearance values can lead to too concave stern buttock lines and in way the propeller sections with potential danger of flow separation and vorticity. In addition limitation in the shaft line length (The propeller shaft length is limited as a maximum to 22 m) cause a certain bluntness of the transversal hull sections in way of the bossings in order to be able to fit inside the hull structure the bearing and the SKF connection to the intermediate shaft. Blunt and full sections upstream in way the bossings and concave shape in way of the propeller disk create longitudinal buttock lines with pronounced curvature and consequently, according to Bernoulli law , the water inside the boundary layer close to the hull behaves like inside a Venturi tube with a rapid increase of section area . A reduction of the water speed downstream of the bossing section shall occour forming a slow and turbulent wake in way of the propeller disk, and in certain extreme case separation may be present Dealing with a podded ship ,bossing are no more required ,clearance can be increased moving the pod propeller as aft as possible since there are no restrictions connected to the shaft length ,and therefore tunnel stern geometry is not necessary and the shape of the stern longitudinal buttock lines can be faired very smoothly achieving a homogeneous ,fast and favourable wake. The only limitation concerning the pod position is related to the possibility to rotate by 360 deg and no part should protude aft of the transom.

In addition thick skegs to locate thrusters holes are no more requested and consequently a further improvement of the wake pattern can be achieved.

4.1.2 Appendages.

For a podded ship all stern appendages have been removed and the improvement of the wake pattern can be easily understood. It is well known that for a twin screw vessel the deepest influence on the

wake is given by the brackets , bossings and shaft line , and efforts has to be made to otimize position and orientation in order to reduce peaks and discontinuities.
The tunnel shape stern shape has in general a higher axial wake fraction Wa and a higher average tangential wake Wt as it aims to create a water turbulence in order to avoid deep wake peaks in way of the brackets. These kind of wake peacks are usually met when Pram type stern forms are used, where the flow is strongly directional following the buttock lines, with a very low amount of tangential components and consequently higher peaks can be observed in way of propeller disk downstream of brackets and bossings. In the case of the podded vessel in absence of appendages there is no need to create this turbulence and consequently the pram type form can be preferred increasing the average w factor and reducing the tangential speeds and improving the propulsion performance of the ship.

4.2 Propeller geometry.

In the definition of the propeller design it is possible to act on a series of geometric parameters in order to reduce the induced loads but it must be considered first in which wake field the propeller is operating .In the case it is working in bad wake field it shall always yield high exciting forces and even putting the greatest efforts and care in the design using the most proper geometry with suitable unloading it shall be just possible to keep within certain limits the negative effects of cavitation and pressure pulses but the vibratory behaviour of the ship shall never be satisfactory Instead when the propeller is working in an homogeneous wake field with smooth gradients and low pecks a suitable choice of blade geometry and load distribution can achieve an optimum behaviour of the blade cavitation pattern with a consequent strong reduction of the exciting forces The selection of the radial pitch distribution , skew ,chord (area) together with and number of blades is fundamental in the reduction of the cavitating volume ,hull pressure and bearing forces.

4.2.1 Skew

Skew is one of the most effective means to reduce the propeller hydrodynamic exciting forces.
When a cantilever straight blade (zero skew angle) is used all sections enter the wake peak together producing "in Phase" pressure signals ,while for skewed propellers sections enter the wake peak gradually one after the other creating "off phase" pressure pulses reducing as a consequence the total induced force .In the selection of the skew angle the designer should not take into account only the hydrodynamic aspects related to hull pressure reduction and efficiency , but it must consider that high skew blades yields to structural problems. For high skewed propellers ,in ahead condition, the highest stresses are not concentrated at the blade root but are usually found in way of the trailing edge between 0.5 and 0.8 r which should be strenthned and faired in order to avoid knuckles which can result to be point of stress concentration . Classification societies require finite elements direct calculation for skew angle grater than 50 deg while for lower values formula could be used. As common practice for merchant ship skew angle are kept below this value even if higher skews could be more attractive under the hydrodynamic point of view in order not to have blade over strenthening. In addition it should be considered that for FPP in backing condition the leading edge becomes the trailing edge with consequent high transitory stresses in way of the tip if high skew angles are used. For a podded propeller there is no more need of high skew degree as the wake peak are very low and the gradient are very smooth allowing consequently a reduction of thickness . Usually , since classification Societies require additional thickness for skew angles larger than 25 degrees. this angle can be taken as limitation to get a thinner and lighter propeller. Once the max skew angle is given there are infinite possibilities to select the pitch distribution along the radius . The choice should be made in order to get a trailing edge sweep suitable to enter the wake peak in the most gradual way .

4.2.2 Area ratio

For the evaluation of the area the criteria used for conventional ship (like Burrill diagram) are difficult to be applied as they have been derived from propeller fitted to conventional hulls. A rough method to select the preliminary expanded area ratio before carrying out detailed lifting surface calculations , is that suggested by Keller formula which seems to give good estimations even if a higher margin could be required (abt 0.05 - 0.1). Ae/Ao=

In the design of the propeller blade using the lifting surface programs it has to be considered that for a pod propeller the inflow angle is varying as pod works and rotate like a rudder. Consequently additional tangential speed components are established changing the load distribution aver the propeller blade. Therefore lifting surface calculation using a certain Kt margin for bubble cavitation has to be performed not only for the straight ahead condition but also for an average value of the rudder angle both for inward and outward rotation. Of course wake in such conditions should be estimated and corrected . It has been verified that such angle can to be limited to 3-5 degrees as it has been proved during sailing in rough weather that this limitation is hardly exceeded.

4.2.3 Number of blades.

As the pod is provided with fixed blades fitted to the hub by means of bolts like the FPP theoretically it should be possible to fit 4, 5 or even 6 blades. The use of high number of blades is generally requested to reduce the pressure level and to change the exiting frequency. It has been emphasised that the wake field in which the propeller is operating is very favourable and therefore an increase of the blade number , with a consequent reduction of efficiency , should not be worth for pressure pulses as just using four blades very low pressure values can be achieved (less than 1 kpa). The selection of 5 or even 6 blades could be requested only if it has been proved that the natural and forcing frequencies are very close to each other and resonant phenomena can arise.

4.2.4 Pitch

It is well known that together with skew , pitch distribution plays a fundamental role in the reduction of pressure pulses Usually the more the tip is unloaded the higher reduction of pressure we can get. At the same time we get a reduction of efficiency and the danger of encountering face cavitation is increased For a conventional ship propeller working in a wake field in order to have a good compromise between efficiency and pressure it is common use to load the mid section between 0.5 R and 0.8 and decreasing the pitch in way of the of tip and the hub. Depending on the difficulty of the project (wake quality , power , speed) the tip pitch can be reduced , in certain extreme cases till 60 % of the value at 0.7 R. For a podded vessel where is the possibility to adopt a load distribution closer to the optimum (Lerbs distribution) even if it is always better to consider a certain amount of tip unloading. In fact the tip vortex thickness is strongly related to the propeller tip loading . Thick and unstable tip vortex is always associated to high load trasnsmission from propeller to the hull with energy distributions over a wide range of frequencies with higher danger of meeting resonance and strong exciting pressures

4.2.5 Thickness

Compared to a conventional ship propeller with the same power speed and rpm ,dynamic direct finite elements calculation have shown lower mean values of stresses in way of the root and the trailing edge , and extremely low fluctuation of the stress . This could suggest the possibility to reduce the blade thickness. But some consideration should be made. As stated above , the propeller rotates together with pod rudder to keep the route and consequently it meets variation of the tangential speed components which should be take into consideration in the fatigue calculation. This rudder movement implies higher variation of angle of attack on the blade profiles and therefore thicker section with wider cavitation buckets could behave in a better way . It should be considered that the pod propeller is not protected by shaft and brackets and consequently more subject to strikes .As for conventional propellers Naca 16 and 66 mean line 0.8 can be used but It should be recommended to use suitable rounding of the leading edge to give the propeller higher resistance against collisions .For this reason ,since bolted in blades are adopted the use of stainless steel could be suggested instead of copper alloys with lower surface hardness .

4.2.6 Propeller design

The most significant difference for the hydrodynamic design of a podded propeller consist in the need to consider the influence on the pressure field of the pod rudder and the gondola. Due to the reduced clearance between propeller and pod rudder it can be seen with a CFD calculation that the pressure fields created in front of the leading edge of the rudder and the gondola are superimposed to the pressure field on the pressure side of the blades. This lead to a modification of the characteristic KT and KQ curves . If we compare the KT and KQ curve measured in open water and those obtained with propeller attached to the gondola we seen that the latter , at the same J value are higher. As the influence of the pod is not easily calculated the problem of a proper calculation of the right Kt Kq curve can be solved applying calibration using the experimental results of suitable stock propellers.

4.3 Clearance

In the case of podded ship the propeller location is not affected d by the length of the shaft line giving the possibility to fit the pod in the most convenient position related to the hydrodynamic aspects. Fitting the propeller in the aft most position allows either to improve the total hull efficiency (the propeller is far from the hull and 1-t is increased) and to increase the tip clearance between propeller and hull. For a conventional twin screw ship the standard clearance varies between 0.25 and 0.30.For a podded ship these value can be increased till 0.35 -0.38 with a corresponding reduction of the pressure pulses.

REMARKS

Using a podded vessel three different factor contribute simultaneously to improve the propeller hull excitation: better hull geometry better wake without appendages influence Increased clearance.

All these factor allows to design a propeller with reduced skew , area and tip unloading which and therefore better efficiency and higher ship speed can be achieved .

5.0 PRESSURE AND CAVITATION BEHAVIOUR

For all pod propeller designed and tested at the cavitation tunnel and vacuum basin the blade surface is free from any kind of harmful cavitation. As a consequence of the very good wake profile the cavitation pattern consists in very narrow band of sheet cavitation along pressure side blade leading edge merging smoothly and gradually to a very thin cavitating tip vortex extinguishing after few revolution ownstream. From an erosion point of view the blades are free from any risk of cavitative erosion and damage even for high values of the pod rudder angle In general, the cavitation phenomena as observed in all tested condition are quite satisfactory with no fluctuations and very stable behaviour. For every tested condition the harmonic analysis of pressure pulses signals has indicated that the main contribution is due to the first blade harmonic decreasing to very low values for the second and the further harmonic orders. Pressure is therefore mainly related to the dynamic displacement effect of propeller rotation characteristics of cavitating blades with a very low energy contribution coming from cavitation sheet growth, development and collapse.

On the contrary ,it should be noted that when high values of second and further harmonic orders occur they are related to an extended cavitation and a thick tip vortex . This indicates a distribution of considerable amount of energy over a wide range of frequencies with consequent higher risk of vibration problems In order to give an indication of the amount of total energy transmitted by the pod propeller to the hull, it is possible to calculate a danger factor R which takes into account the contribution of all the harmonic components of the integrated vertical force FZ. This factor allows a risk analysis of propeller pulsing force but is not related to the vibratory behaviour of the vessel as it doesn't consider the structure geometry. Values below the allowed margin fully guarantee a quite and safe behaviour of the propeller, under the vibratory point of view. Higher values mean that propeller starts to exert its hydrodynamic action over the hull and care should be taken in the design and scantling of the structure to prevent vibrations. For all tested pod ships very low levels of hull pressure fluctuations were attained.(As an average a value of 1.5 kpa in the worst condition in the most exited point.) According to the calculated danger factor R , the pod propeller develops a vertical total force which is below the allowed margin and this should guarantee a very smooth vibratory behaviour of the vessels also in the MCR condition.(Maximum continuos power).

6.0 CONCLUSIONS

From the large series of tank testing carried out on a set of cruise podded vessels following consideration can be made. Propulsion improvements are mainly related to rudder and shaft line removal but the adoption of pram type geometry with inserted central skeg, both for existing transformed ship or completely new vessels, can improve ship performances. As a tendency this hull pram geometry gives better propulsion performance compared to wing or tunnel shape, but at the same time a worse vibratory behaviour, and therefore for ship like passenger vessel with conventional propulsion preference is normally given to the second solution even if more expensive. As the wake field for the podded vessel proved to be very smooth and uniform with low loads induced by the propellers , it seems possible to fit the pram geometry also to high comfort class vessels like cruise ships, reducing consequently steel manufacture problems and production cost. The average possible improvement using a pod solution compared to a conventional propulsion can be close to 10 per cent which makes the system attractive for ship designed with diesel electric power plant. In case of transformation from a diesel mechanical solution , electric conversion efficiency of about 0.92 has to be taken into account in the global power balance making the system less appealing. These expected improvements are related to tank measurements and verification shall be made after completion of sea trail to confirm the validity of these predictions.