New Hydrodynamic Aspects of Double Ended Ferries with Voith-Schneider Propeller
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1. Introduction
Voith-Schneider propellers (VSP) have proved themselves as reliable propulsion systems for double-ended ferries (DEF) for more than 65 years. The VSP gives DEF excellent maneuverability and realizes the propulsion with very good efficiency [1].
In recent years, Voith Schiffstechnik has improved the efficiency of the VSP by using the CFD technology - coupled with experimental methods - and especially further deepened their knowledge of the interaction between the propeller and the ship. This paper presents the results of a joint research project of the SVA Potsdam and Voith Schiffstechnik and shows selected results of a DEF with 4 VSP. It has to be mentioned that a common DEF will be equipped with only two VSP. The installation of four VSP may be required by only very specific design requirements like limited draft or high power requirements.

Numerical and experimental methods have been used to improve the hydrodynamics of DEF with Voith-Schneider-Propeller. The flow around the hull is calculated both using potential-theoretical methods and by solving the Reynolds Average Navier-Stokes equations (RANS). In order to bring about better knowledge of the interactions between the propeller and the ship’s hull, a measuring device was developed which allows simultaneous measurement of the thrust and transverse force of the individual VSP. The propulsive power of the initial design and an optimized ship hull were compared. Based on the methodology used, a significant reduction of the propulsive power requirement was achieved. The calculation processes were automated to the greatest degree possible, so that optimization of hull ship forms of DEF is possible in a very efficient way.

2. Functional principle of the VSP
The application of the Voith-Schneider-Propeller in ferries guarantees very good maneuverability, high safety and economical efficiency [2],[5]. Figure 1 shows a modern double-ended ferry with 4 VSP and figure 2 shows a new ferry with 2 VSP.

Fig. 1: DEF FRISIA, 4 x VSP 16KG/100 - each VSP 470 kW input power, working in the North Sea in extreme shallow water
Fig. 2: DEF CORRAN, 2 x VSP Gr. 16KG/100 - each VSP 470 kW input power, working in Scotland
The functional principle of the VSP is briefly explained to help to understand the technology of the VSP and its employment in DEF.

1. rotor casing
2. blade
3. kinematics
4. control rod
5. servomotor
6. bevel gear
7. reduction gear
8. driving sleeve
9. propeller housing
10. thrust plate
11. roller bearing
12. oil pump

Figure 3 shows a sectional drawing and a 3D-CAD illustration of the rotor casing and the kinematics. The Voith-Schneider propeller generates thrust by means of profiled blades projecting from the ship bottom and rotating around a vertical axis. The blades are arranged in a rotor casing that is flush with the ship bottom. As the VSP simultaneously generates propulsion and steering forces, additional attachments - such as propeller struts, ship rudders, gondolas, shafts, etc. - are not necessary in ships fitted with a VSP. The control rod(4), as shown in fig. 3, allows the very quick change of the thrust in x-y coordinates.

Figure 4 shows the forces acting at the propeller for selected blade positions. Lift changes during revolution due to the unstationary flow at the propeller blades. The forces acting across the desired direction of thrust cancel each other, whereas the forces acting in thrust direction are added over the propeller circumference. Figure 5 shows the lift conditions as a function of the cycloid path for a stationary observer. Figure 6 shows the pressure distribution of a VSP based on CFD calculation.
Voith-Schneider-Propeller are working with very good efficiency in all direction [3],[4].

![Fig. 6: Pressure distribution on a VSP blade as a result of CFD calculation](image1)

![Fig. 7: Comparison of the swept area of a Voith-Schneider-Propeller compared to a screw propeller](image2)

Voith-Schneider propellers run at very low speeds. These are only approx. 25 % of the speeds of screw propellers of comparable size and power. The reasons for the low speeds can be summarized as follows:
- The rectangular jet area of a VSP is about twice as large as that of a screw for specified installation conditions (Figure 7).
- The blades are arranged at the outer rotor circumference. The resulting flow due to rotor rotation and ship speed is constant over the blade length. With screw propellers, the flow increases as the propeller radius increases.
- Unstationary flow conditions exist at the blade. They allow greater effective angles without flow separation.
- The VSP generates thrust in two stages in the front and rear rotor half, analog to contra-rotating propellers.

The low speed is associated with high torques, resulting in a robust design, which implies increased weight as a disadvantage, however.

**The advantages of the low speeds of VSP are:**
- Long life, particularly of the bearings and seals.
- Insensitivity to foreign objects, such as driftwood and ice. It can also be noted that the blade usually impacts such foreign objects with its front edge, where the blade has the highest section modulus relative to the effective direction of the attack force.
- Very safely dimensioned components.
- Low pressure impulses on the ship's hull.

The speed influence on the characteristics of the VSP is analog to diesel engines (slow and fast running diesel engines). With these, the speed is also an important influence on the technical parameters.

### 3. Comparison of two DEF
It was the goal of the project to make hydrodynamic improvements based on an existing design of a DEF. For this purpose, the following methods were used:
- Potential-theoretical calculation of the wave resistance using the program KELVIN of the SVA
- Calculation of the friction resistance and detection of separation using the program COMET. The calculations with COMET do not take into account the influence of the free surface yet.
- Model experiments at the SVA Potsdam: Development of a measuring method to measure the
individual VSP thrusts in the ship; model-based measurement of suction and wake, and propulsion tests.

Figure 8. and 9. show the two ship hulls studied. Variant A (fig. 8) is the initial variant, variant B (fig 9) is an optimized hull as a result of the research project. An important boundary condition of the design is the limited draft.

Fig. 8: Variant A (initial design)

Fig. 9: Variant B (optimised design)

The main data of the ship are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{PP}$</td>
<td>122.00</td>
</tr>
<tr>
<td>$W$</td>
<td>22.00</td>
</tr>
<tr>
<td>$D$</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Propeller data (4 VSP):

VSP 32GII/225

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blade diameter [m]</td>
<td>3.20</td>
</tr>
<tr>
<td>Blade length [m]</td>
<td>2.250</td>
</tr>
<tr>
<td>Chord length [m]</td>
<td>0.405</td>
</tr>
</tbody>
</table>

Variant A was designed in such a manner that optimized flow condition for the aft propeller is provided. However, this is associated with a resistance increase. Therefore, development of variant B tried to achieve an optimum with respect to hull drag and the interaction between the VSP and the ship’s hull.

4. CFD studies

4.1 Calculation of the wave drag using the potential theory

Results of the calculation with the program KELVIN are shown in figure 10 and 11. For a description of the program KELVIN, refer to [6] and [7].

In an early phase of the research project, fins were originally provided for both variants. Analysis of
steerability has shown, however, that these fins can be eliminated as the VSP already has a very high stabilizing effect due to its vertical axis of rotation. The calculations were carried out for 12 kn. A comparison of the original variant to the optimized variant shows a significant reduction of the wave resistance by approx. 30%.

**4.2 Calculation of the wave resistance**

The solution of the RANS makes it possible to calculate the viscous resistance and the detection of flow separation. For the ship hulls shown in figures 8 and 9, numerical calculations were carried out. The program COMET solves the Reynolds Average Navier-Stokes equations based on the Finite Volume Method [8]. As the turbulence model, the standard k-ε model was used. The calculation have been carried out in model scale. Results of the calculation are shown in figures 12 - 17. Figures 12 and 13 show streamlines of both versions. It is evident that the initial design has severe flow separation. That of course brings about increasing resistance. The variant B by contrast shows a very smooth flow pattern.

Figures 14 and 15 make possible a closer look at the separation phenomena at the bow of the ship. Figures 16 and 17 do the same for the aft.
The bilge knuckle initiates a vortex at the fore part and also at the aft part of the hull. The optimized variant B does not show such pattern. The reduction of the resistance is obvious. The CFD calculation showed a 35% reduction of the viscous resistance.

The question so far unanswered is, what will be the interaction between the aft propeller slipstream and the hull of the ship. At present only a test on model is available for answering this question.

At the moment a project is also running which makes it possible to calculate both the flow around the VSP and the flow around the ship hull. For this purpose as a first step a simplified VSP-model based on the momentum theory and the full simulation of the flow around the hull is used.

In the following chapter the model test will be described.

5. Model tests with a DEF propelled by 4 VSP
5.1 Description of the tank facilities and the model
Model tests were carried out at the Potsdam Ship Model Basin. Figure 18 shows the towing tank and its main dimension which guarantee a unrestricted water condition.
For the test only the optimised model was used because for the initial design (Variant A) Voith Schiffstechnik has experimental results in its files.
Tank dimension:
Length: 280 m
Wide: 9 m
Depth: 4.5 m

Fig. 18: Towing tank of SVA Potsdam

Fig. 19 shows the model of the Voith DEF with the integrated model propeller.

Fig. 19: Test model of the Variant B (optimised design) at the SVA Potsdam

5.2 Development of a novel thrust measuring system for VSP
To be able to assess the propulsion behaviour of a ship, the knowledge about the propulsion coefficients is essential. Within the VSP model propeller, provided by Voith, there is no individual equipment for measuring the trust and side forces. Therefore SVA developed a special measuring system for VSP models. In principle it is a balance. Inside this balance the VSP model is bedded on gages. The balance houses the VSP models with 200 mm diameter. Measurands are propeller
thrust, propeller torque and transverse force of the propeller.

Fig. 20: Thrust measuring system for VSP, 3D-CAD and integrated in the ship hull

The system is shown in figure 20 as a 3D-CAD picture and as integrated into the ship hull of the model. Two of these systems were produced to measure simultaneously the forces at the fore and at the aft model propeller.

5.3 Model test results

Propulsion

Propulsion tests were carried out for a speed range of 9 to 16 kn. The model was equipped with four VSP models. At the port side thrust and torque were measured, at the starboard side only the torque was measured. All VSP had the same RPM for each speed.

The effective wake fraction number was calculated for both ends. The result is plotted in figure 21.

Fig. 21: Wake fraction numbers at both ends

The wake fraction numbers are negative at both ends. At the aft end the flow is accelerated by the slip stream of the forward propellers. At the fore end there is a accelerated flow because of the bilge

Fig. 22: Thrust deduction numbers at both ends
keel radius.
Extra tests were carried out in order to determine the thrust deduction numbers for the propellers at each end. This was made by means of different thrust loads. During each run the RPM at the one side was adjusted to the value determined from the propulsion test while the propellers at the other end ran at different loads. A resistance test was not necessary. Figure 22 shows the result. The higher thrust deduction fraction at the fore end is typically for double ended ferries. That is since the slip stream of the propeller hits the hull and there are losses because of rising friction. Compared with double ended ferries with rudder propellers the thrust deduction number is lower at the fore end and higher at the aft end. This is one reason why DEF can run with a very good efficiency by having an equal load on the fore and aft propeller.

**Measuring of wake and slip stream**
Flow measurements were made at the design speed. The measurements were made behind the fore and aft running VSP. Also the wake field of the aft VSP was measured while the forward VSP’s were running. All measurements were made on the port side.

Fig. 23 shows the flow 2.5 m behind the forward running VSP. The measuring section is orthogonal to the coordinate system of the ship while the VSP is inclined by 4°. Therefore the vertical components in the range of zero indicate a flow direction towards the hull. Small vortices occur on the blade tips.

Behind the aft VSP the vertical flow component has a slope of 6° – 8° towards the bottom of the ship.

![Fig.23: Flow field 2.5 m behind the fore running propeller](image)

![Fig.24: Flow field 2.5 m behind the aft running propeller](image)

![Fig.25: Wake field of the aft VSP with running forward VSP's](image)

The wake was measured in a plane of the most forward point of the VSP diameter with the same slope. The nominal wake is in a range of –0.1 up to 0.2. There are horizontal flow components to the outer side of the ship. But they are lower than 10% of the ship speed. The reason for this effect...
may be the wide bottom of the ship.

**Comparison of the delivered power**

The figure 26 shows the PD-values of the fore and aft propeller, for which the individual measurements of the forces were made as described above. The propellers were running with the same number of revolution. It is interesting that both propellers have the same power consumption.

![Figure 26: Power consumption of the front and aft propeller](image)

Figure 27 shows the comparison between the initial design and the optimised design. This comparison makes clear that the optimised lines give a much better hydrodynamic characteristic. The modification of the lines has given a reduction of the resistance which was shown by the potential calculation of the wave resistance and by the RANS calculation of the resistance based on friction effects. That was as expected after the CFD calculation.

An important additional result achieved by the model test is that the continues bilge radius has no negative influence on the interaction between the hull and the propeller.

![Figure 27: Comparison of the delivered power of the initial design (Variant A) and the optimised design (Variant B)](image)
6. Conclusions

Intensive research has been carried out by the SVA Potsdam and Voith Schiffstechnik with the aim of improving the hydrodynamic characteristics of double ended ferries with Voith-Schneider-Propeller.

Based on the systematic application of numerical tools (potential wave resistance calculation with the program KELVIN and using the RANS code COMET) a remarkable improvement of the power consumption of a DEF with 4 VSP has been achieved. The results achieved in this project were only possible because the CFD method offers much more insight into the flow field around the hull of DEF. The optimisation measures have been proven by the model tank test in an impressive manner.

With the new measuring system it is possibility to determine all propulsion factors. Especially the wake and the suction can be determined.

At present there is a project of Voith Schiffstechnik for CFD calculation including the effect of the VSP and furthermore calculating the wave resistance and the effect of the viscosity simultaneously in COMET.

The investigations have proven that a DEF equipped with VSP will have different design criteria for ship lines compared to DEF with conventional or other omnidirectional propulsion systems.

Voith Schiffstechnik and SVA Potsdam offer the results of this research project to ship owners, ship yards and consultants. We will give the necessary support for the design and optimisation of new double ended ferries.

7. Literature


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