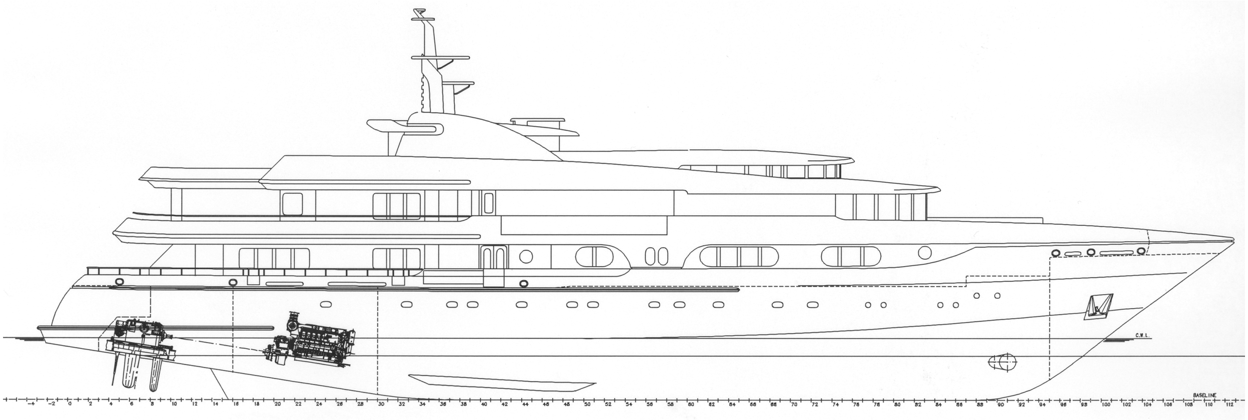
Voith Turbo
Voith Turbo Marine GmbH & Co. KG
Alexanderstraße 18
89522 Heidenheim, Germany



Paper to 18th International HISWA Symposium on

Yacht Design and Yacht Construction

November 15-16, 2004, Amsterdam

Cycloidal Propulsion – the Quiet Maneuvering Propulsion for Large Motor Yachts

Dr. Dirk Jürgens[a], Torsten Moltrecht[b], Marcel Flipse[c]

The vertical axis cycloidal or VOITH SCHNEIDER Propeller (VSP) has by no means reached the limits of its development. A new generation of VSP with enhanced hydrodynamics and improved construction is ready for introduction into the market.

Use of the latest computational fluid dynamic methods (CFD) allow continuous improvement of hydrodynamic and hydroacoustic performance. New blade profiles with higher efficiency have been developed and hull-designs using the VSP are now the subject of continuous research and improvement.

A new propeller generation with higher maximum input powers is under development. For the redesign of each component an industry-leading structural analysis FEM program is used. This provides the power of linear and nonlinear structural analysis capabilities to provide reliable structural simulation results. New construction principles for key-components such as blades and main bearings have been developed. The first ship-sets of VSPs with 6 blades (instead 5) and improved hydrodynamic efficiency have been already installed and successfully tested during trial runs.

Benchmark model scale tests have been performed showing superior efficiency of VSP over other competitive propulsors. A new quiet VSP is in the development pipeline with a second input pinion and non-metallic gears for low noise operation.

Yacht owners invest considerable resource in acquiring a vessel that is comfortable and safe. But yachts tend to roll uncomfortably while at anchor in secluded bays, causing discomfort. The thrust of the cycloidal propulsors may be used to compensate the wave exiting moments at all speeds, especially at zero speed.

A new example of enhanced cycloidal propulsion is the VOITH CYCLOIDAL Rudder (VCR). This modified VSP, with only 2 blades, is the latest propulsion and maneuvering device to be adopted for ocean-going vessels requiring higher operational speeds. It has two operating modes: a ***passive*** *mode that allows the VCR to act as a conventional rudder for cruising speed and an* ***active*** *mode that works in the same way as a VSP to ensure a high degree of quiet maneuverability at slow speeds.*

---

[a] Manager of Research and Development Department, Voith Turbo Marine GmbH & Co. KG, Heidenheim, Germany
[b] Naval Architect, Voith Turbo Marine GmbH & Co. KG, Heidenheim, Germany
[c] Product Manager, Voith Turbo B.V., Twello, The Netherlands

1. HYDRODYNAMIC PRINCIPLE OF CYCLOIDAL PROPULSION

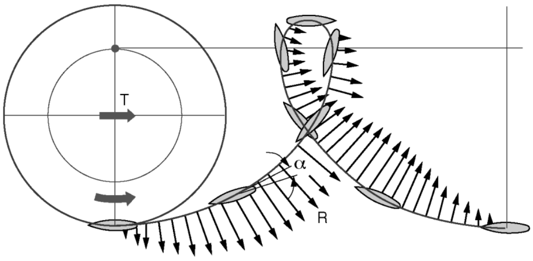


Fig. 1: Cycloidal path of VSP blade with hydrodynamic lift

The idea of this unique propulsion and maneuvering system was initially developed by the Austrian engineer Ernst Schneider in 1926 [1]. The principle of thrust generation by a VSP is comparable to a fish's fin or a bird's wing action, which also produce simultaneous thrust and steering forces. Animals with such movements have the optimal adaptation to their living environment.

On a VSP, the blades project vertically below the ship's hull and rotate on a rotor casing about a vertical axis, having an oscillatory motion about its own axis superimposed on this uniform rotation. The blade's oscillating movement determines the magnitude of thrust through variation of the amplitude (pitch), the phase correlation determines the thrust direction between 0 and 360 degrees. Therefore an identical thrust can be generated in any direction. Both variables - thrust magnitude and thrust direction - are controlled by the hydraulically activated kinematics of the propeller, with a minimum of power consumption.

Consideration of the processes on each blade during one revolution provides the simplest explanation of the resultant hydrodynamic forces. By superimposing the rotary movement of the rotor casing on a straight line perpendicular to the rotational axis (to represent the movement of the vessel), the blade of the VSP follows a cycloid (Fig. 1). To generate thrust, the blade profile has to be turned against the blade path by the angle *a* by moving the steering center inside the kinematics. Through this, hydrodynamic lift will be generated at right angles to the resultant velocity (perpendicular to the cycloidal path). The magnitude of the lift depends on the angle of attack *a*, the inflow velocity, and the profile characteristics. The lift varies during the blade's revolution. Integration of the components of the lift forces created over the entire circumference shows:
- the lift components acting in the direction of motion result in the thrust
- the lift components acting at right angles to the direction of motion cancel each other out.

Thrust can be produced in any direction merely through movement of the steering center. Due to the rotational symmetry, identical thrust can be generated in all directions. For free-running conditions, a steering force can be produced in addition to longitudinal force up to available pitch and power limits.

Unlike screw propellers, the speed through the water over the whole VSP blade is constant. Blades are not twisted. There is a clear zero-thrust position of the kinematics independent from the speed of rotation. The rectangular effective propeller area of a VSP is about 60% larger than the area of a screw propeller (circle). The VSP may be seen as a "twin" propeller as each blade is used twice during each revolution. Further, the VSP characteristically works at a very low speed of rotation.

The hydrodynamic principle of the cycloidal propulsor forms the foundation for control of thrust in magnitude and direction steplessly, precisely, and quickly. Further the VSP allow low noise operation during all working conditions, especially maneuvering; a significant advantage for large motor yachts.

Below are some examples of ships that employ advantages of the hydrodynamic principle of cycloidal propellers.

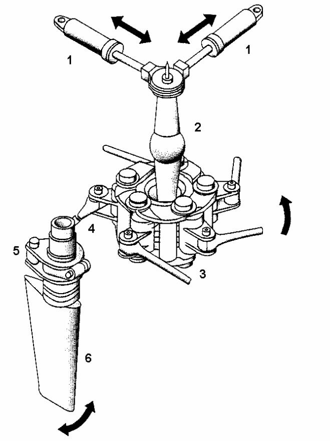
Fig. 2: U.S. Navy MHC Kingfisher

Several thousand cycloidal propellers have been produced by Voith in more than 75 years. Key examples include the class of highly maneuverable and quiet mine counter measure vessels deployed by the U.S. Navy (Fig. 2). The full engine power may be used for maneuvering in any direction within 360°.

The French buoy tender "Chef de Caux" regularly maintains navigation and research buoys (Fig. 3). Two VSP are installed in this ship, one at the bow the other aft, giving an unique maneuverability.

Fig. 3: French buoy tender "Chef de Caux" with two VSP size 12

2. CONSTRUCTION PRINCIPLES OF CYCLOIDAL PROPELLERS



servo motors/actuators (1)
control rod (2)
lower spherical bushing (3)
connecting rod (4)
actuating lever (5)
blade (6)

Fig. 4:
crank type kinematics

The hydrodynamic required blade oscillation is produced mechanically by the crank-type kinematics inside the VSP. The links of each blade actuating system are directly supported by the lower spherical bushing of the control rod. The control rod can be displaced eccentrically and is connected to the crank, which pivots around the bearing pin fitted to the rotor casing. A connecting rod transfers this movement to the blade through the blade-actuating lever. (Fig. 4)

The rotor casing of a VSP carries 4, 5, and now, 6 blades around its circumference. The blade axes lie parallel to the propeller's main vertical rotation axis. The thrust bearing axially (vertical) supports the rotor casing, the weight of the rotating parts, and the tilting forces generated by propeller thrust and gear tooth pressure. Radially, a roller bearing centers the rotor casing and transmits the thrust through the propeller housing to the ship's hull. A reduction gear flanged to the propeller housing and a bevel gear drive the rotor casing.

A control rod activates the kinematics using two hydraulic servomotors arranged at 90 degrees to each other. A speed servomotor controls the pitch component for longitudinal thrust (ahead and astern) and a steering servomotor controls the pitch component for the transverse thrust (port and starboard).

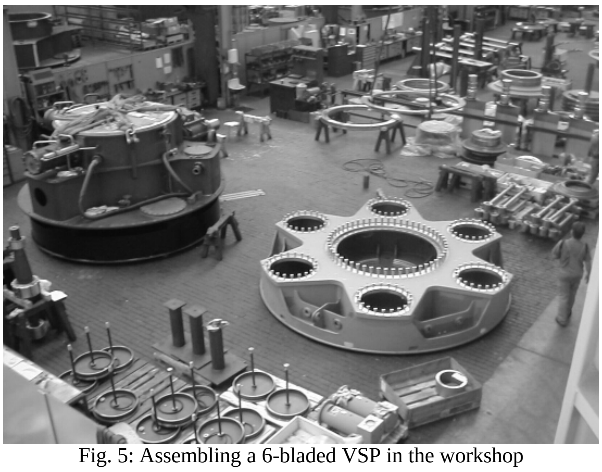


Fig. 5: Assembling a 6-bladed VSP in the workshop

3. TOOLS FOR VSP-ENHANCEMENTS

Hydrodynamic enhancement of the VSP is based on three pillars: computational fluid dynamics, model scale experiments and full-scale test. For the redesign of each component an industry-leading structural analysis FEM program is used.

Computational fluid dynamics

Fig. 6: CFD calculated pressure distribution on 6-bladed VSP

Using a highly sophisticated computer program (Comet), the three dimensional non-stationary flow around the VSP is simulated. The flow field is divided into about 1.5 million small volume elements. For each volume, the physical constraints, including viscosity, are estimated.

Comet is written using a blend of several numerical techniques. Together, they make a numerical method that is very efficient regarding the computer memory needed. A sequential solution method is suitable for application on parallel computers. However, for Comet the SPMD (Single Program Multiple Data) model is adopted. In this approach, each processor runs an identical program but only solves for its own set of data. To solve the global problem, the computational domain needs to be distributed over all the processors via domain decomposition. Space and time parallelization are implemented in Comet using PVM (Parallel Virtual Machine) and MPI (Message Passing Interface) message passing libraries.

Three PC clusters (each 8 x P4 3.0 GHz) with Linux operation system are used to perform CFD calculations. Each processor is an independent single computer with its own operating system and address space. Sending and receiving data through a connection network, by employing MPI effects the communication between the processors. With this equipment, typical calculation time for a full scale set of data for a VSP (abt. 1.5 Mio CV) is about 20 hours. Fig. 6 shows an example of the pressure distribution on a 6 bladed VSP.

Well known is the fact that not only the propeller itself but the ship's hull and appendages have significant influence on vessel performance. As a partner in ship design and navel architecture of the shipyards, Voith assists in optimization of the total ship as a system.

Only if the VSP is correctly installed can its advantages be fully utilized by the operator. In Fig. 7 is provided as an example a CFD calculation for two VSP with a new nozzle plate. This kind of simulation requires significantly more CV's and calculation time.

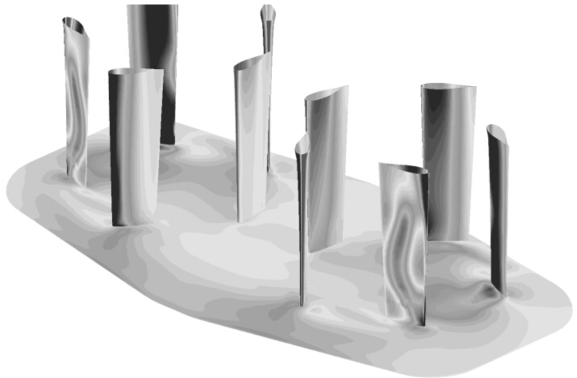


Fig. 7: CFD calculated pressure on new nozzle and 2 VSP

Model-scale experiments

Fig. 8: Voith´s circulation tank facilities.

Detailed model-scale experiments are regularly performed with the VSP in Voith´s circulation tank facilities in Germany (Fig. 8 and Fig. 9) and in independent research laboratories around the world. The Voith tank has a measuring area of 6.0 m x 2.2 m x 1.1m is suitable for unlimited measurement time.

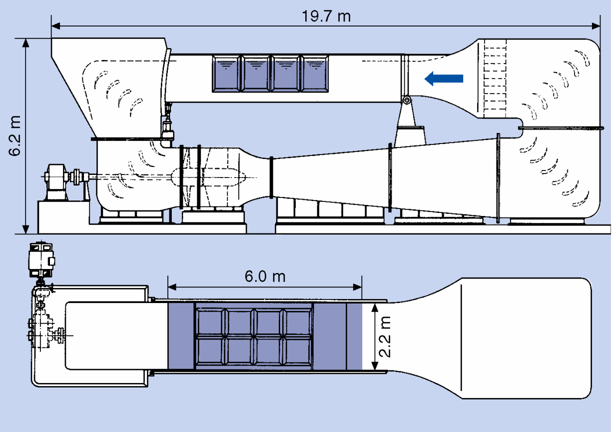


Fig. 9: Voith´s circulation tank facilities.

Even now, with the latest computer technology and best CFD tools, model scale tests deliver high value reliable information. Further calibration of CFD tools is very important. Results of the numerical calculations and model scale experiments correspond well.

Full-scale Tests

Fig. 10: 6-bladed VSP´s as installed on Ahuriri for full scale tests

Regularly full-scale measurements on vessels equipped with VSP's are performed. Underwater and airborne noise and vibration measurements, bollard pull tests, free running, and maneuvering trials are standard. The correlation of expectations with reality yields high value information for future predictions. Detailed knowledge of existing and historic data builds confidence in results and allows system enhancement.

Enhanced Design and Calculation Tools

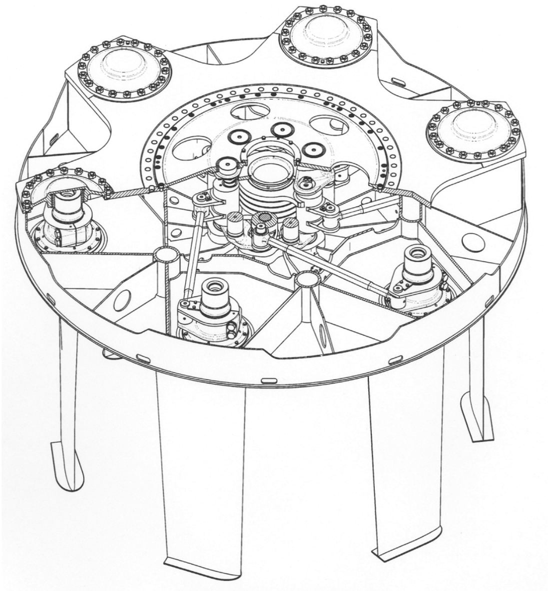


Fig. 11: 3D-CAD model of 6-bladed kinematics

Although components of the hydrodynamically enhanced VSP's are based on proven components, re-design of each component is supported by an industry-leading structural analysis program. ANSYS provides the power of linear and nonlinear structural capabilities to deliver reliable structural simulation results. The nonlinear contact functionality allows the analysis of complicated VSP assemblies.

CFD calculated global propeller loads (thrust, torque, moments) are input data for a simplified three-dimensional kinematic model. Dynamic loads are estimated with this simplified VSP analysis. For the peak-load and several other positions, detailed static analyses are performed. An accurate mathematical model of the critical components is built by the 3-D CAD program IDEAS (Fig. 11), incorporating material properties, real constants, boundary conditions etc. and transferred to the FEM program. For the static analysis the governing equation is [K]{u}=[F], where [K] is the structural stiffness matrix and {u} is the displacement vector. The force vector {F} includes the pressure distribution on the blades as a directly transferred CFD result. Nonlinearities such as contact surfaces are solved by applying the load gradually. This can obtain an accurate solution. The cut-boundary technique is used to get more accurate results in regions of special interest, if the mesh of a global structure is too coarse. Displacements calculated on the cut boundary of the global model are specified as boundary conditions for the more finely meshed sub-model. Below (Fig. 12) the stress in a VSP rotor casing is shown.

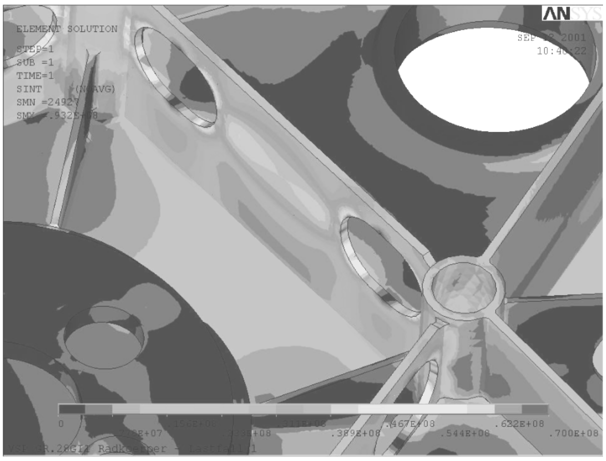


Fig. 12: Stress in VSP rotor casing

4. ENHANCEMENTS ARCHIVED FOR THE CYCLOIDAL PROPELLER

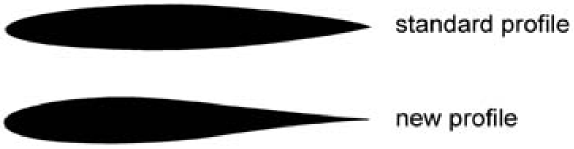


Fig. 13: Profile of the blades

The efficiency of a VSP is significantly determined by the profile of the blade and blade number. In this way, Voith has succeeded in finding a profile that clearly improves the hydrodynamics (Fig. 13). The combination of modern simulation technology and the proven model test technology has made possible a significant increase in VSP performance. Evaluation of new profiles in actual model tests have measured significantly higher efficiencies.

Optimized profiles have more steel volume and more undesirable weight. To reduce the weight of the blades, a new technology for the blade production had to be developed. Weight is reduced by drilling holes from the lower side into the forged blades. By FEM, the maximum diameter of 90 mm and length of up to 2500 mm for a 3.6 m diameter VSP blade was established. Fig. 14 below shows a blade from the first shipset in the workshop during September 2003.

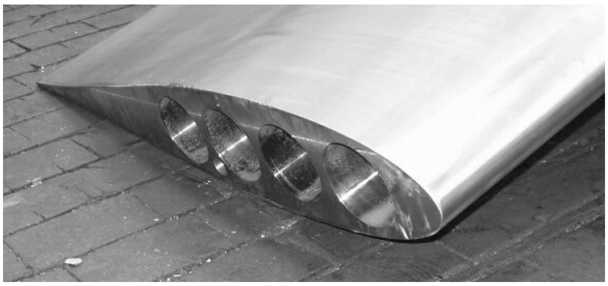


Fig. 14: VSP blade as build with weight reduction holes

To avoid the tip vortex on VSP blades, endplates have been developed (Fig. 15). Endplates increase bollard pull on the tugboats and reduce vibration and noise on all applications. All new VSP's are equipped with endplates as shown in Fig. 15. Endplates can be added to existing VSP's by welding. Customers who have retrofitted endplates have reported big improvements in regard to bollard pull and vibration. For yachts and other vessel with stern arranged VSP, special designed endplates are subject of ongoing development.

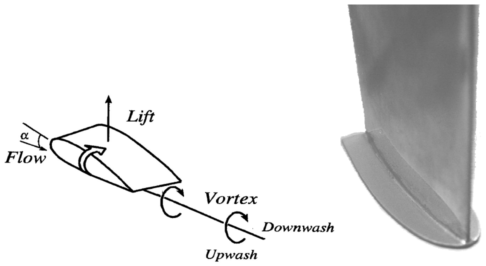
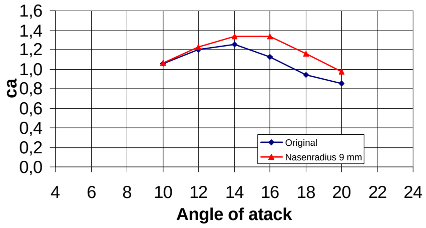


Fig. 15: Tip vortex and blade as build with endplate

The 4800 kW *Ahuriri* (Fig.: 10) for Port of Napier is equipped with the first shipset of two 6-bladed VSP 32R6/210-2's of the new generation. Arranging 6 instead of 5 blades per VSP allows an increase to the power-density and reduces installation costs per power. As noted previously, blade shape and interactions between individual blades were optimized using CFD tools. Sophisticated new kinematics were designed in 3-D-CAD based on existing experience and components (Fig. 11). Several components were optimized for strength and weight using FEM. The high power-density allowed installation of the VSP in a very compact tug with only 22.5m length - L_{WL}. Performance of the new generation of VSP's was carefully measured during shipyard trials in 2002 in Singapore. The bollard pull predicted, based on model tests and CFD, was exactly as expected. Noise and vibration were significantly reduced in comparison to earlier VSP designs. Total vessel performance was excellent.

Based on this positive experience the larger VSP 36R6/255-1 for 3400 kW was delivered at the end 2003 to Norway. The new generation VSP's will allow use as main propulsion for large vessels as very large yachts.



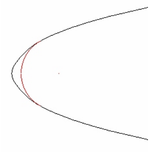


Fig. 16: Modification of nose radius

Even very small modifications in blade shape may enhance performance of the VSP. Fig. 16 shows the nose radius or leading edge of VSP blade in two variations. CFD-calculations showed significantly improved lift coefficients (c_a) after this very small modification. As standard practice, all blades of newly delivered VSP's have an optimized leading edge.

Based on customer requests, direct comparisons of VSP's to contra rotating Z-drive's have been performed by Marintek (Norway) for a platform supply vessel [2]. The models used the same fore-body with the stern part of the hull optimized for the individual propeller. Fig. 17 shows the stern with the VSP installed. Displacement and length was identical for both hull alternatives. The resistance (P_E) of the Voith proposed bare hull was slightly higher than the competition's hull. Nevertheless the propulsion tests ended with an advantage for the VSP solution. In total this shows a VSP with blades optimized for free-running can have higher efficiency (η_D) than contra rotating Z-drive. Based on the data, it is clear that fuel consumption with VSP will be lower. Further open ocean station keeping can be much easier, and radiated noise is lower with the VSP.

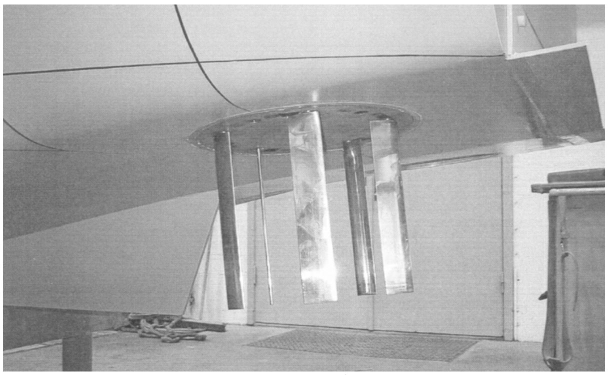


Fig. 17: Detailed view of PSV with VSP

Below the most important propulsion data as measured at Marintek with the following definitions: CRP – Contra Rotating Twin Propeller; VSP – Voith Schneider Propeller; D – draft; P_E – effective power (resistance); n – revolutions of propeller; P_D – delivered power; η_D – efficiency.

	CRP				VSP			
D	P_E	n	P_D	η_D	P_E	n	P_D	η_D
[m]	[kW]	[rpm]	[kW]	[-]	[kW]	[rpm]	[kW]	[-]
5,2	1659	158	2631	0,63	1711	61	2439	0,70
6,0	1973	160	3180	0,62	2115	64	3048	0,69

Not only the propeller, but the ship as system has to be optimized. Now it is possible to investigate the flow around the hull with the 3-D viscous flow analysis to optimize resistance and propulsion early in the design. Below, in Fig. 18, is an example of a pre-optimization vortex on a VSP propelled ship. Ahead of the model scale test for this project, several ships did their trial run in the numerical flow tank and best alternatives could be selected early in the design process. At the final stages, this vortex was omitted. See [3] for details.

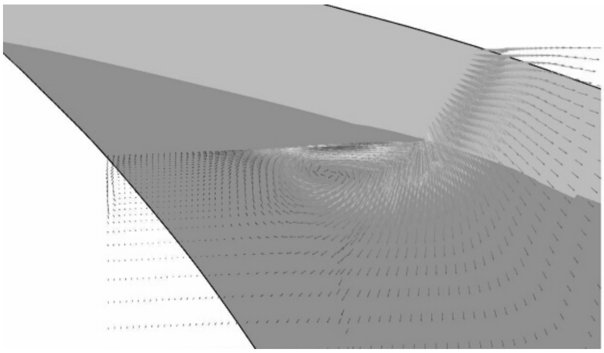


Fig. 18: Pre-optimization: a vortex increases the resistance

In the future, flow calculations for hull optimization will include the influence of the VSP. For this, a special numerical model is developed together with SVA Potsdam. First test calculations have been performed with a simplified source model for each VSP on a 4 VSP propelled ferry (see Fig. 19).

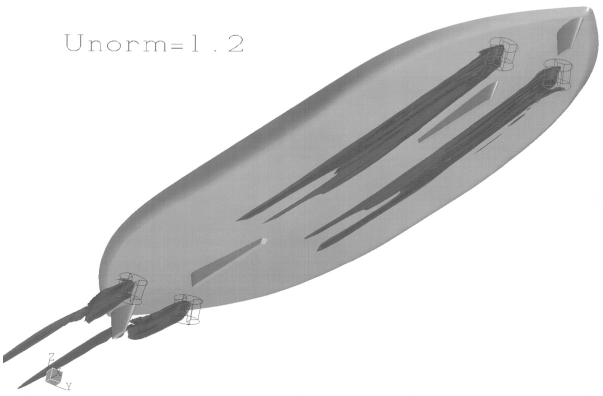


Fig. 19: Simulation of propeller -wake

During quiet operation, only small percentage of installed engine power is normally used in yachts for DP or roll damping at zero speed. It is advantageous to use the main propulsor for station keeping and special operations as propeller blade area is designed for the much higher free-running power. With a low specific propeller load, the number of revolutions can be reduced for quiet operation and the large VSP blade area result in excellent hydroacustics.

As a new improvement, VSP's intended for special quiet applications will be equipped with a second input shaft. This second shaft will drive the propeller via a special non-metallic pinion designed for low-load operation. Already in operation, the VSP's for mine counter measure vessels have exhibited very low structural noise and vibration levels with special steel gears. This modification will improve the quiet operation capability of the VSP (see Fig. 20) further.

Fig. 20: Non-metallic pinion in development

5. ROLL DAMPING AT ZERO SPEED WITH CYCLOIDAL PROPELLER

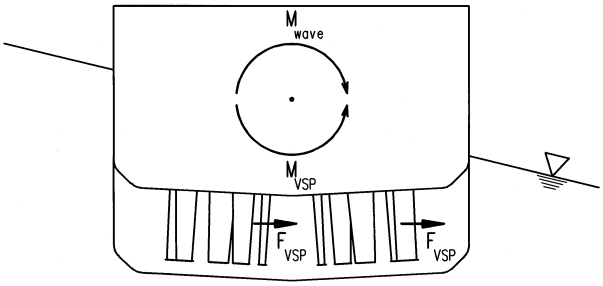


Fig. 21: principle of roll reduction by cycloidal propulsor

Yacht owners invest considerable resources in acquiring a vessel that is comfortable and safe. But Yachts tend to roll uncomfortably causing discomfort to the passengers. So far fin stabilizers have been widely used as a hull stabilization system. They are very effective but only above a certain ship speed. Fin stabilizer have almost no effect for a still standing or slow sailing vessel. But one of the aims of yacht owners is to be able to anchor in secluded bays in a relaxed atmosphere. This aim is lost if the vessel starts to roll.

Voith is developing a new technology for reducing the roll motion especially at slow speed and for a still standing vessel, e.g. a mega-yacht on anchor. The existing VSP or the VCR can produce the necessary moment for damping the roll motion at relevant sea states. Fig. 21 explains the principle of roll reduction by cycloidal propulsor. The moment created by the propulsor forces counteracts the wave exciting moment.

The efficient roll reduction is possible because:
- The VSP has the capability of creating thrust very efficient in all direction
- The thrust can be changed via x-y coordinates very fast
- The steering unit can easily be integrated into the overall steering system of the VSP
These three facts are determinedly for an efficient roll reduction. There is no additional system necessary for the reduction of the roll motion. The VSP can fulfill multifunctional task:
- Propulsion
- Maneuvering (incl. dynamic positioning)
- Roll reduction
That is also an important aspects for reducing the overall maintenance efforts of the vessel.

If the ship is equipped with one or two VCR then at higher speed there is a roll reduction in passive mode possible. The VCR acts like a conventional rudder and as a rudder-roll-stabilization system with the same performance. If the ship is equipped with VSP the side thrust component for roll reduction may be superimposed to the propulsion thrust by intelligent control.

The University of Technology in Hamburg-Harburg (Prof. Söding) has made simulation for a corvette (Lpp = 80 m, GM = 0,8 m) which is very similar in regard to underwater hull to a yacht, equipped with two VCR as an auxiliary propulsion and maneuvering system. The calculation have been carried out for a vessel at zero speed. For the simulation the strip theory has been used. The Pierson-Moskowitz-Spectrum (T1 = 10,5 s, μ = 90°) was applied. Fig. 22 shows the significant roll angle in irregular see with and without an active VCR roll damping.

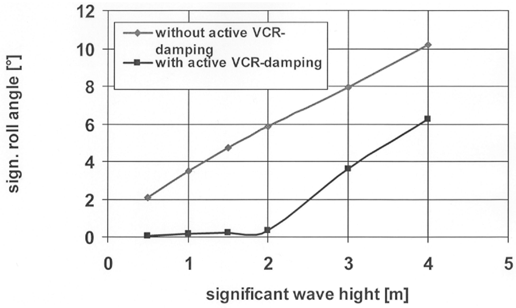


Fig. 22: Calculated roll answer of a 80m corvette with and without active VCR-damping in irregular see.

It is obvious that the roll motion can be reduced remarkably for a yacht like vessel up to 2 m significant wave height and also for higher waves there is still a good reduction.

If a vessel is equipped with two VSP as a main propulsion system, then a more efficient stabilisation energy is available. Fig. 23 shows the calculated roll answer in irregular see of an offshore supply vessel (Lpp = 86 m, GM = 1,3 m). There is even up to 7 m relevant wave height a remarkable roll reduction possible.

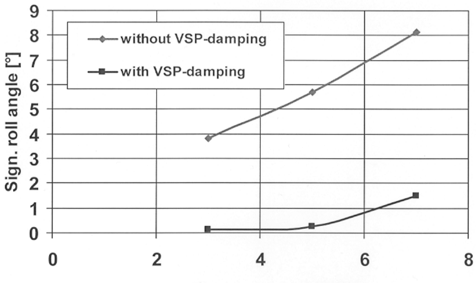


Fig. 23: Calculated roll answer of a 86m offshore supply vessel with and without active VSP-damping in irregular see.

Fig. 24 shows the principle of the steering system of the cycloidal propulsion for roll stabilisation. A hull roll sensor signal gives additionally to the two pitch signals information to the control unit of the VSP/VCR. The control unit changes via proportional valves and two hydraulic cylinder the pitch in x and y direction. For the still standing vessel the roll sensor signal has a high priority together with the dynamic positioning requirements. If the vessel is sailing then the pitch signals are more dominant. The control algorithm can either integrated into the Voith-control unit or supplied as an external additional unit that also can give dynamic positioning and auto pilot signals.

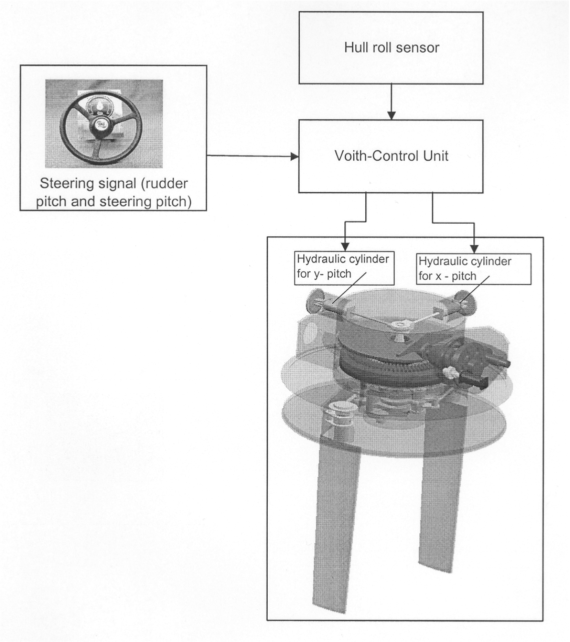


Fig. 24: Control principle for roll damping.

6. VOITH CYCLOIDAL RUDDER

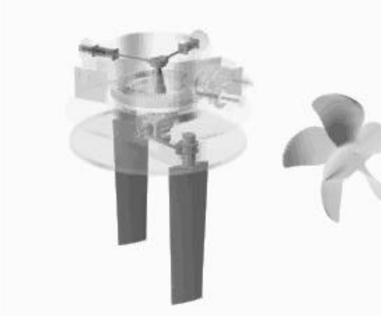


Fig. 25: VCR and conventional propeller

Based on the VSP, the cycloidal rudder (VCR) is under development (Fig. 25). It is a new propulsion and maneuvering system for ships requiring maximum maneuverability over their entire speed range, extremely low acoustic signatures, precise thrust control, and auxiliary / emergency propulsion capability. This modified VSP replaces the traditional rudder and is also an independent auxiliary propulsion system.

The VCR has two operating modes: A passive one, in which the VCR acts as a conventional rudder for movement ahead at cruising speed while the conventional propeller drives the vessel, and an **active** one, in which it operates in the same way as a VSP to ensure a high degree of maneuverability at slow speeds. The active mode enables precise, quick, and safe maneuvers even at the lowest speeds. It also provides the low noise propulsion and best fuel economy for DP or loitering on station with main engines secured.

As with the VSP, the cycloidal rudder has a rotor casing with a vertical axis of rotation. Two rudder blades lying parallel to the axis of the rotor casing project from it below the vessel's hull. This rotor is turned via a reduction gear by a low noise electric motor.

VCR Passive Mode of Operation

The passive mode is used at cruising speeds. The rotor casing does not continuously rotate but instead is slightly rotated from the longitudinal to produce steering forces much like a conventional rudder (Fig. 26). Thus, the locked VSP blades are adjusted relative to the inflow and transverse forces for steering are generated.

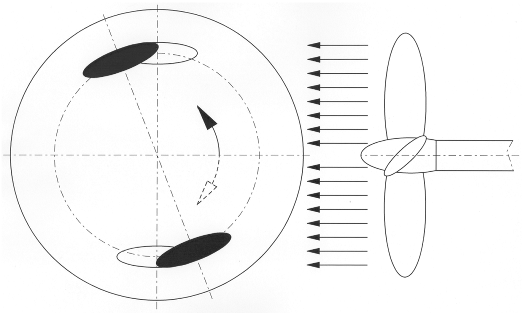


Fig. 26: Principle VCR in passive mode

Conventional rudders are designed for producing sufficient rudder forces with small inflow speeds. At high vessel speeds the rudder area is oversized because of the squared dependence of rudder force to speed. Oversized rudders produce additional drag resistance. As this passive mode for VCR is used only for high speed operation, rudder area may be designed much smaller and appendage losses will be greatly reduced.

VCR Active Mode of Operation

In the active mode of operation, the VCR rotor casing is rotated and the system functions like a VSP where controllable thrust, step less in direction (0-360°), and variable in magnitude is produced. Therefore an identical thrust can be generated in all directions. Both variables - thrust magnitude and thrust direction - are controlled by the hydraulically activated kinematics of the VCR with a minimum of power consumption. Main propulsion can be reduced to stand-by condition, CP-propellers may be in sailing mode while FP-propellers can be wind-milling.

Active mode of operation is selected for slow speed operation when high maneuverability is needed, e.g. during roll damping at zero speed, helicopter landing, going along-side or in the harbor, both in narrow channels and while mooring and getting underway. Maneuvering inside harbors without infrastructure and tug assistance will be possible. In emergency situations, including loss of main propulsion, the VCR can provide take home capability.

Unlike fin-stabilizers, the VCR allows roll stabilization even without vessel forward speed. The thrust direction of active VCR may be electronically controlled to oppose roll motion. As thrust direction can be varied quickly and precisely, excellent station keeping allows comfortable parties and helicopter landing in sea-states much higher than today's operational limits.

VCR Development by CFD

With the above explained numerical tools, the hydrodynamic performance of several blade shape modifications for the VCR in active as well as passive mode of operation was calculated. For the individual application an optimized solution can now be selected.

VCR Development by Model Experiments

Detailed model experiments have been performed with the VCR in Voith´s circulation tank facilities for active as well as passive mode of operation (Fig. 8). Blade profile, blade shaft position, as well as scale effects have been varied. Based on the model experimental results and the CFD calculation, a program for predicting forces/thrust in project stage was developed.

As an example of model experiment results in the Voith circulation tank, an open water efficiency diagram is provided in Fig. 27. This was collected using a model VCR with blade-orbit diameter of 200 mm.

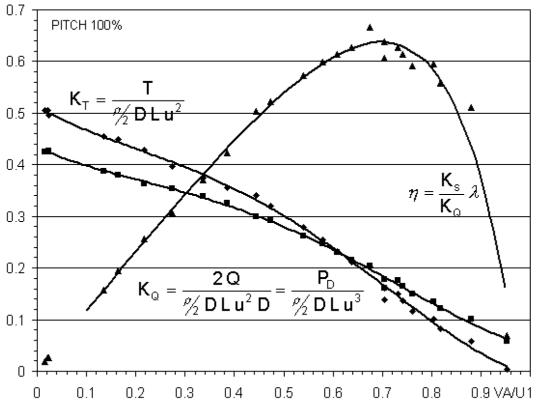


Fig. 27: VCR model scale results

Again not only the rudder, but the total ship, is the subject of interest. For a low noise vessel, maneuvering and propulsion tests have been performed at SVA Potsdam [4] and Marin Wageningen [5] with active and passive VCR.

Fig. 28: Scale maneuvering tests with VCR for 100 m research vessel

Several VCR blade shapes and sizes have been evaluated resulting in optimum solution combinations for both. As required, the optimum mix of propulsion efficiency in active mode and steering forces in passive mode can be selected by the vessel operator.

VCR Development using Full-Scale Tests

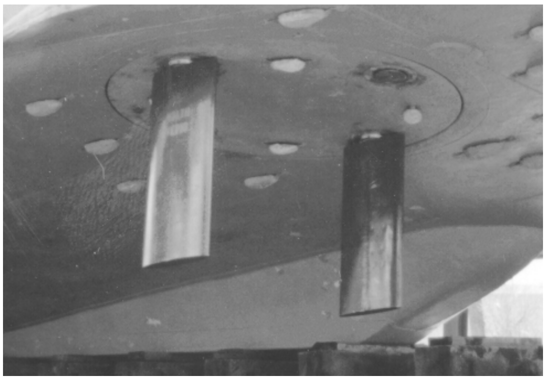


Fig. 29: VCR as installed on "AURORA"

Full scale tests with active VCR have been performed in the training vessel, "AURORA", operated by the "Seefahrtsschule Leer". The existing VSP size 14E/90 was modified to a VCR with blade orbit diameter 1.4 m (Fig. 29). Two of the existing 4 blades have been removed and replaced by seal plugs. With several blade shape modifications the active mode of a 2-bladed VSP similar to a VCR was tested in the North Sea. The 40 m vessel performed well with active VCR during all maneuvers. Comprehensive measurements with regard to noise, thrust, vibration, power consumption, and maneuvering behavior were performed. The evaluation showed good correspondence of the full-scale measurements with numerical and model scale based predictions. Now that the development tools are calibrated, further development is based on solid foundations.

Operational Aspects of VCR for Yachts

The dual mode of operation of the VCR provides a number of key properties that are important for yachts. Yachts must have high transit speed capabilities for reaching owner specified area, but must be able to linger on station for long periods with very low power consumption for ensuring smoke free operation and minimal onboard noise.

Conventional rudders in today's yachts are designed to produce sufficient rudder forces with small inflow speeds. At high vessel speeds, the rudder area is oversized because of the squared dependence of rudder force to ship speed producing additional appendage resistance. As a consequence of the alternative modes of operation of the VCR, as active propeller (slow speed) and passive rudder (cruising speed), the required rudder area can be designed much smaller for the required passive service speed. Especially for higher speed yachts, reduced rudder area significantly reduces the appendage resistance of the rudder. Due to the reduction of rudder area, acoustic noise radiation will also be influenced positively in free running.

To secure passenger comfort, quiet operation is important. On a vessel with a VCR, the main propulsion may be completely shut down during DP in secludes bays and active VCR may propel the vessel, resulting in much lower radiated noise. The VCR is a 360-degree vectorable propulsion system for low speed operation. With full thrust in any direction achievable even at zero ship speed, the VCR effectively gives the yacht unprecedented maneuverability.

Redundancy of propulsion and steering by installing the VCR, which is completely independent from the main propulsion, can also be important for the yachts's safety and survivability. In case of a loss of main propulsion, the active mode of the VCR can act as emergency propulsion with full maneuverability and offer take home capability.

High maneuverability is of major importance if a yacht has to enter restricted waters. With a VCR, this maneuverability is available from a low noise propulsion device. As with the VSP for special applications, VCR will be available in special low noise versions. Special gear technology will assure quiet operation. The design of the VCR will be based on the proven design of the quiet VSP for mine counter measure vessels.

With the maneuvering capabilities of the VCR, movement astern, turning on the spot, and lateral movement with step less transition inside harbors and alongside piers is possible. This is of major importance in harbors without adequate tug fleets. With the VCR ships can safely execute difficult maneuvers that, previously, would have required the assistance of tugs. The VCR gives the yacht what amounts to its own built-in, directly controllable, tug for precise maneuvering. Implications for maneuvers like man-overboard recovery are obvious.

Finally, an unusual capability is available with the VCR – stabilization as described above.

Advantages of the VCR for yachts include:
- Low resistance rudder for high speed operation.
- Low acoustic signatures especially during maneuvering.
- Improved maneuverability in comparison to conventional propulsion arrangement.
- As propeller for main propulsion for low speeds (CP-propellers may be replaced by FP-propellers).
- Redundancy of propulsion and steering (take home capability)
- Roll stabilization even during stand-still of vessel is possible.

Further details on the VCR are available on a paper presented at SNAME annual meeting [6] or in German magazine Schiff & Hafen [7]. The application in double-ended ferries is described in a paper presented in 2001 in Norway [8]. A judgment on the development process of the VCR is given in ONRIFO Newsletter #17 [9].

7. SUMMARY

Both types of cycloidal propulsors are well suited for future yachts. The VOITH SCHNEIDER Propeller may be used as a highly efficient main propeller giving high power for maneuvering. The VOITH CYCLOIDAL Rudder, an ideal complement to advanced propulsion systems, is now available for specification in the next generation of yachts.

[1] Birgit Jürgens, Werner Fork; Faszination Voith-Schneider-Propeller: Geschichte und Technik; Hamburg, Germany; Koehler; 2002; ISBN 3-7822-0854-4
[2] Marintek Report No. MT60F02-066 601956.00.01 and .02; Trondheim; Norway; 2002
[3] T.Waclawczyk, M.Palm; Conference on Hydrodynamics in Ship Design, HYDRONAV; Numerical prediction of ferry resistance with RANS turbulence model and the Volume of Fluid method for the free surface"; Gdansk; Poland; 2003
[4] SVA Potsdam Report No. 2829 M1135; Potsdam; Germany, 2002
[5] Marin Report No. 18611-1; Wageningen; The Netherlands; 2003
[6] Torsten Moltrecht; SNAME Annual Meeting 2002; Paper 13 - Development of the Cycloidal Rudder for Very Maneuverable Combatant Ships; Bosten; MA; 2002
[7] Torsten Moltrecht, Michael Palm, Sven-Dietmar Schmidt; Entwicklung des Cycloidal-Ruders; Schiff & Hafen pages 43-46; Hamburg; Germany; März 2002
[8] Dirk Jürgens, Torsten Moltrecht; 1st International Conference on Double-Ended Ferries 2001; Combining Cycloidal Rudder and Conventional Fixed Pitch Propeller for Fast and Very Manoeuvrable Double-Ended Ferries; Norwegian Institute of Chartered Engineers; Molde; Norway; 2001
[9] Larrie D. Ferreiro; Naval Architecture & Ship Systems Newsletter #17; Office of Naval Research International Field Office; August 2003; http://www.onrifo.navy.mil/reports/2003/Voith_Cycloidal_Rudder.doc