Development and impact of the eVSP: an intelligent propulsion system for safe, sustainable and efficient navigation

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Abstract

This paper introduces and explores the development of the Electric Voith Schneider Propeller (eVSP) as an evolution of the well-recognized mechanical version (VSP) patented almost 100 years ago (1926). This study highlights the extraordinary technological contribution of Voith's Maritime Division R&D department, which aims to encourage and promote reliable and efficient solutions for the improvement of the maritime industry regarding the concepts of digitalization, electrification and decarbonization based on the International Maritime Organization (IMO) goal of driving a 50% reduction in greenhouse gas emissions by 2050. Throughout the document, different perspectives will be presented in order to represent the original system concept and its evolution, seeing several technological considerations, the impact of the solution in Latin America and the potential applications in the region due to the technical advantages of this propulsion system especially for rough navigation and operational conditions reflecting the environmental contribution in terms of fuel consumption, energy savings, low emission and noise and high efficiency related on the operational life cycle cost impact.

Key words: Cycloidal, Kinematics, Maneuverability, Propulsion, Reliable.

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Introduction

Developed almost 100 years ago (patented in 1926), the Voith Schneider Propeller (VSP) is a concept that's means prompt, safe and precise maneuvering, even under adverse conditions. An extraordinary propulsion and steering system developed to generate thrust in all directions, suitable for a wide range of applications, from (harbor) tugs and ferries to various types of offshore vessels. The VSP is distinguished by its high reliability and low maintenance requirements. Its minimum power demand translates into low fuel consumption while at the same time maximizing safety for vessels, passengers, and the environment [3].

Considering the electrification of the drivetrain as an important step towards a more eco-friendly shipping industry, Voith developed the Electric Voith Schneider Propeller (eVSP). This combines all the advantages of the system with the electric motor of the Voith Inline Thruster. The result is a reliable, energy-efficient, environmentally friendly and compact drive unit that is ideal for use in yachts, ferries, tugs, tenders, passenger vessels, and offshore applications. Like the conventional VSP, the eVSP achieves maximum thrust in all directions, continuously variable and with maximum precision. The powerful, directly integrated electric motor (permanent magnet motor) delivers high torque and a fast response without any gears whatsoever. This means that it ensures a more direct and almost loss-free conversion of the electrical drive power into thrust, while keeping noise emissions to a minimum. Due to the low maintenance requirement for the robust electric propeller, the subsequent costs for servicing are drastically reduced [1].

In harsh operational conditions such as those prevailing in different scenarios like high-risk harbor maneuvers, inland navigation with low depth or high garbage presence, scientific, military, or touristic profiles regarding the noise and comfort and the maintenance of offshore equipment with demanding tasks. Voith eVSP represents a proven technology for reliable performance, efficient electric drive system for maximum effectiveness with a compact design to suit individual requirements and improved sustainability [3].

The Voith Schneider Propeller (VSP)

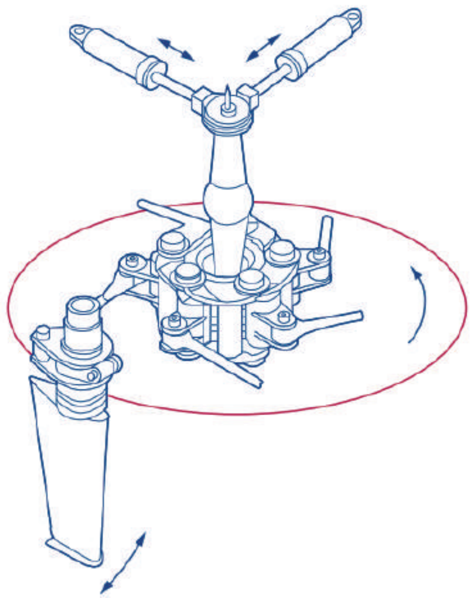
As a Concept

The VSP, as controllable pitch propeller principle, is strikingly simple and fascinating at the same time: A rotor casing fitted with four or five propeller blades rotates around a vertical axis. As is the case with the tail fin of a dolphin, a superimposed oscillating motion of the blades around their own axis generates thrust. The magnitude of thrust is determined either by the rotational speed of the rotor casing or the amplitude of the blade angle oscillation. The blade angle determines the direction of thrust [3].

Generation of this oscillating motion is via a kinematic mechanism (see Fig. 1). Since the VSP simultaneously generates propulsion and steering forces, there is no need for additional appendages such as the VSP design propeller brackets, rudders, pods, shafts, etc., In the VSP, the direction of thrust can for example be changed from full ahead to full astern at a constant speed of rotation without creating disturbing transverse forces or requiring changes affecting the main engine. With the VSP, positions can be maintained precisely in all applications, also allows precise and stepless thrust generation; where propulsion and steering forces can be varied simultaneously [3].

As a result of its vertical axis of rotation, the same amount of thrust can be created over 360°. Blades with hydrodynamically shaped profiles and end plates create thrust with a high degree of efficiency [3].

Fig. 1. Kinematic principle [3].



Two servomotors per propeller enable steering to X/Y coordinates [3].

Hydrodynamic principle of thrust

Considering the blade movement, (see Fig. 2) the eccentricity (e) also referred to as pitch of the VSP is defined as [3]:

$$e = \frac{ON}{D/2} \quad (1)$$

The pitch of the VSP can vary within a range of e ≤ 0.8. The advance coefficient λ of the VSP is the ratio of the inflow velocity on the propeller (VA) to the circumferential velocity of the blades (u):

$$\lambda = V_A/u \quad (2)$$

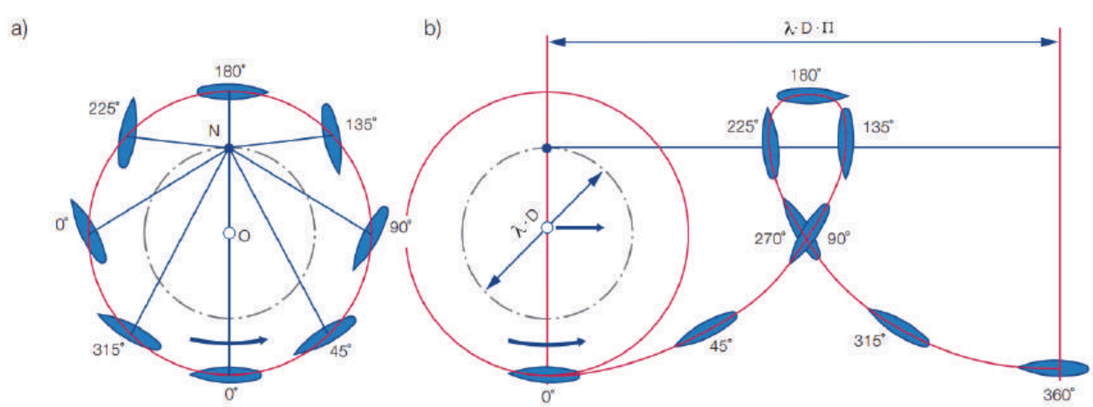
The circumferential velocity (u) at the blade circle, with rotor speed (n) and blade orbit diameter (D), is given by:

$$u = \pi \,.\, D \,.\, n \quad (3)$$

The rotational speed is only approx. 40% of that found on screw propellers of comparable size and power. The low rotational speeds result in high torques, which calls for a robust design. This leads to a higher weight, high degree of efficiency, long service life, especially of bearings and seals, and reduced vulnerability to obstacles such as driftwood and ice, low hydroacoustic signatures and a very high shock resistance [3].

As the advance ratio increases (vessel speed increases while propeller speed remains constant), the steering forces also increase. Since the VSP is a variable-pitch propeller, high steering forces can be generated by very rapid changes in pitch. These are used efficiently for roll stabilization and dynamic positioning [3].

Fig. 2. Cycloidal path of a VSP blade [3].



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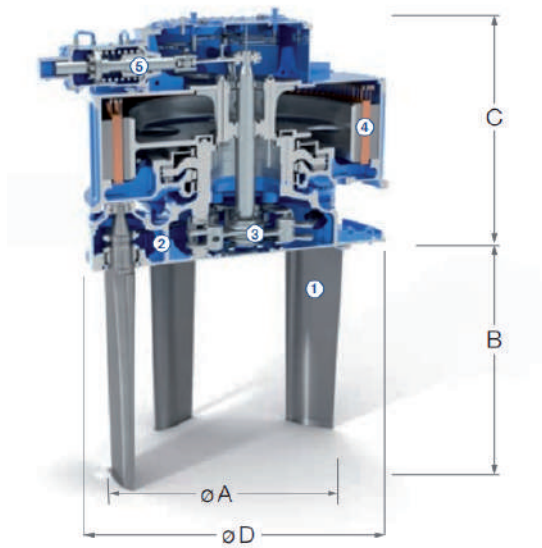
The Electric VSP (eVSP)

Electrical integration as evolution



1. Blades
2. Wheel body
3. Kinematics
4. Electric motor
5. Hydraulic cylinder

As a first development step of the new eVSP, a suitable electric motor principle was selected and adapted to the special features of the VSP. It was considered that the VSP operates at a very low rotational speed, requires a high torque, and is often used in the partial load range. Therefore, the highly efficient technology of the permanent magnet synchronous motor (PMSM), also known as torque motor, is the ideal solution. This modern electric motor technology is characterized by very high efficiency in the entire motor map [1].

For this purpose, the PMSM was integrated directly into the housing of the VSP and a special model is developed for this purpose. The result of the development is shown in Fig. 3. The PMSM was realized with the innovative, space-saving toothed coil technology and the buried magnet method. The buried magnets ensure very high functional reliability [1].

Compared with the conventional VSP, the following elements were substituted: *The bevel and primary gearbox, Asynchronous machine, Shaft line, Cooling & mechanical steering controls*. Additionally, with the high efficiency of the PMSM torque motor and the elimination of gearbox and shaft line losses, the efficiency increased in the range of 4% to 12% depending on the load [1].

In addition, the modified oil system of the eVSP requires a much lower oil volume, which reduces operating costs. Its readiness for use of bio-oil improves the ecological footprint. And thanks to its low weight and compact design, the eVSP can also be integrated in a very space-saving way, allowing for greater scope in the design of the engine room [1].

A new approach with the digital revolution

With the intention of improve the maneuverability and seakeeping of the VSP applied on different types of vessels and concepts. Tailor-made models have been designed and simulated based on high performance computational fluid dynamic (CFD) calculations, simulator studies and finite element analysis, aimed to develop reliable prognosis of the propeller response according to different parameters and scenarios (see Figs. 4, 5) [4].

Also, several model evaluations in the Voith test tank supported by well-known international research institutes, and regularly simulator studies (see fig 6 & Fig. 7) provide to the R&D department of Voith maritime division a comprehensive mix of great tools, skilled engineers, a can-do attitude, and powerful hardware and software coupled with decades of experience. This allows experts not only focus on propellers, but also on the entire vessel response [4].

Including: *Model trials, CFD studies, Basic layouts of vessel designs, as generated arrangements, lines plans, installation proposals, Bollard pull and speed forecast, Escort force calculations,*

Fig. 4. Design loop, based on CFD and simulator [4].

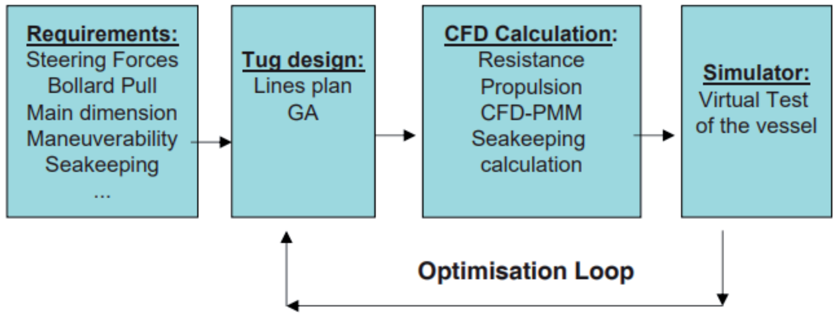


Fig. 5. CFD model simulation [8].

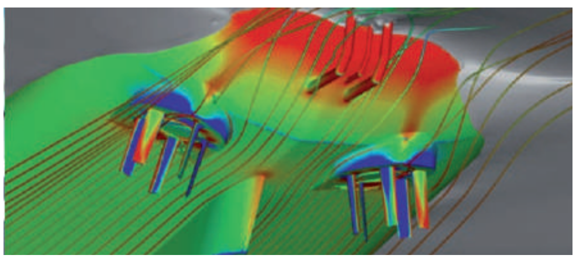


Fig. 6. Model tests in Voith test tank [8].

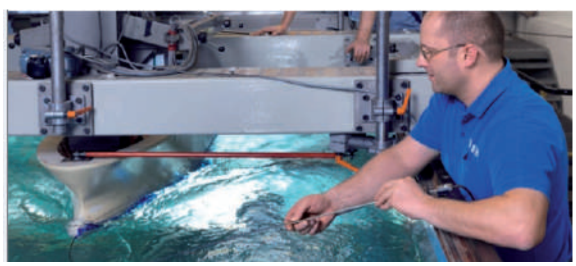


Fig. 7. Maneuvers simulation studies [8].

Dynamic Positioning calculations, validation of the simulation models, scale effect analysis and new developments [4].

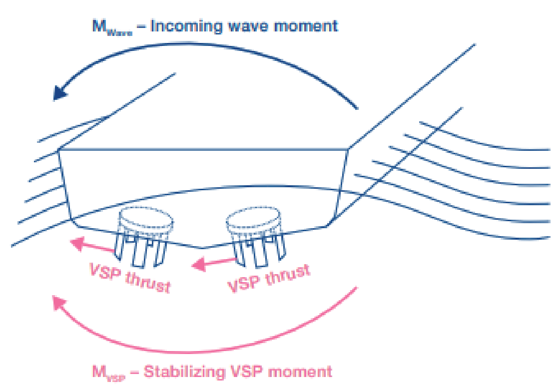
Roll Stabilization Upgrade

Both under dynamic positioning and when traveling full speed ahead, Voith Roll Stabilization (VRS) counteracts up to 90% of all the rolling motion of a ship. This not only improves the on-board comfort of working ships, ferries and yachts, but also increases the safety of passengers and crew. In addition, offshore support vessels, for example, can continue working even in heavy seas thanks to the VRS. Due to these extended operating times, the ships can be operated more cost-effectively (see fig. 8) [1].

OnCare Health Marine

The OnCare Health Marine is a condition monitoring system with a remote support connection. It provides valuable, intuitive

Fig. 8. Moment and force during ship's rolling [5].



diagnostic information in real time for multiple systems. Customers can use OnCare. Health Marine to: Increase the availability and reliability on board, increase ship safety and reduce maintenance costs, change their maintenance strategy from reactive to preventive and beyond [7].

Fig. 9. OnCare Health Marine sensor overview [7].

The VSP legacy in the Latin America Environment

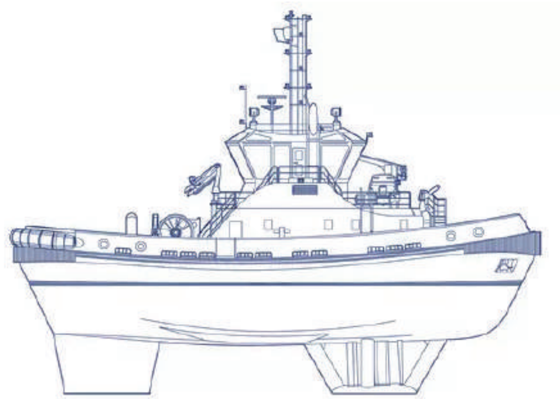
Voith towing solutions for harbor operations

This concept is a standard-bearer for safety and has revolutionized ship-handling across the world, with more than 900 Voith Water Tractors (VWT) currently operating in over 200 ports. This model offers reliability, speed and precision for towing and escorting, salvaging, firefighting, oil pollution control and offshore supply logistics [3].

VWT's unique capabilities make it a key element of any port's complex safety systems. Its superior dynamic ship handling means less expenditure is required on shore-side facilities such as breakwater extensions and channel dredging. A VWT fleet helps boost port traffic density, permitting vessel approaches in poor weather conditions [3].

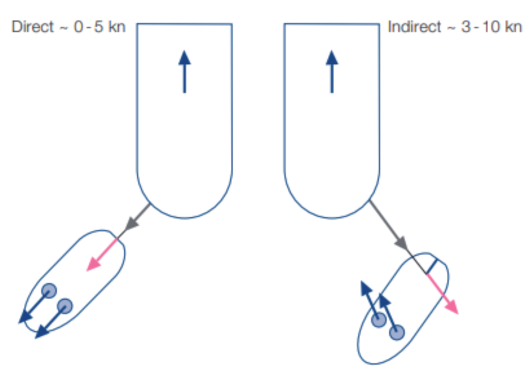
With this model (see Fig. 10) several operators confirm the swift, sensitive, stepless thrust variation in direction and magnitude, regardless of VWT speed, considering an easily controlled, redundant steering logically related to movement of the VWT, also a robust marine engineering using top-quality materials and high resistance to external ship-handling stresses in rough conditions, and an extremely long service life [3].

Fig. 10. The classic Voith Water Tractor (RAL) design.



Most common operational profile is related to escort mode. With the VWT is possible develop a double static bollard pull maneuver (see Fig. 11) considering the "direct" method with engine power creating the necessary forces through the propulsion system and the "in direct" method that use the hydrodynamic force of the hull [3].

Fig. 11. Double static bollard pull maneuver [8].

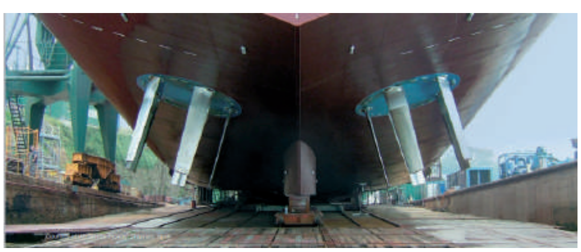


In *Colombia* after 40 years of exceptional behavior, a fleet of VWT (VSP 30R5-250) still working at the Caribbean cost and represent a versatile, maneuverable, reliable and safe system for marine operations, supporting excellent results in the docking and departure maneuvers of cargo vessels. The specific requirements for performance and propulsion equipment for operation in rough weather and a large functional aft working deck for efficient ship handling operations, promote the Voith powerful technology (about 60 tons and free running of 13.6 knots) as the best solutions for those scenarios even against the z-drive technology.

At the *Panama* Canal, another impressive reference of VWT (VSP 28GII/185) with +35 years of service with a high operational profile represent the high resistance to external ship-handling stresses in rough conditions, and an extremely long service life of the Voith units.

For *Mexico*, a fleet of VWT (VSP 30R5/250-2) are used at an oil and gas maritime terminals on both coasts of the country. During the rainy season, the rivers where the terminals are located drag a large amount of floating objects (shoaling, rope jamming and vegetation) that means a high risk and interesting challenge of resistance and reliability representing advantages in terms of life cycle cost, downtime and high capacity for escort duties and maneuverability that is practically unaffected by river currents.

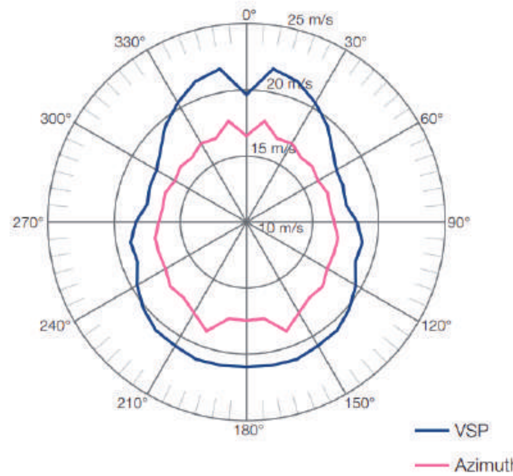
Fig. 12. Double static bollard pull maneuver [8].



Dynamic position on offshore applications

For modern offshore vessels, good Dynamic Positioning performance is a standard requirement. This allows operations at offshore structures, such as wind turbines or oilrigs. The DP performance depends on how fast and accurate the propulsion systems can counteract environmental conditions, including wind, current and/or waves. The most common practice is to validate the vessel performance and to compare different vessels by a static and dynamic DP plots, which considers the vessel motions, the dynamic environmental conditions and the reactivity of the propulsion system [5].

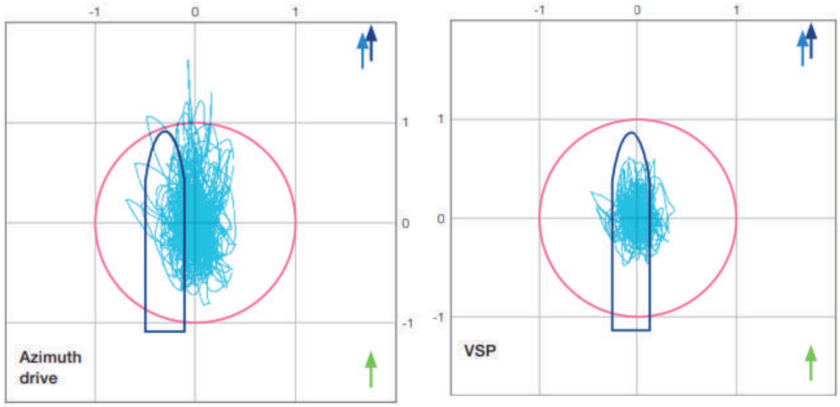
Fig. 13. Comparison of dynamic DP plot [5].



The VSP offers huge advantages when it comes to DP operations. The fast and extremely precise thrust allocation in all directions is the main reason for outstanding performance. When the vessel starts to move away from its position, the VSP can react immediately and brings the vessel back into the requested position. Other propulsion systems can't react as fast as the VSP can [5].

Fig. 14, shows the difference of a VSP driven vessel versus a vessel with rudder propellers at the same input power conditions. A more accurate positioning is also helpful for personnel transfer and crane or helicopter operations. When the vessel is able to work at higher sea state or in high wind conditions, it remains in full operation longer, which is a huge benefit for operators [5].

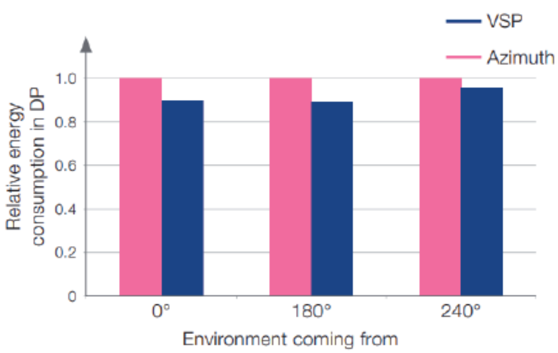
Fig. 14. Results from a simulator study for a wind farm service vessel with different prop arrangements for identical wind, weather and wave conditions clearly shows the difference in DP accuracy [5].



About the fuel consumption @ DP, the ability of the VSP to react faster than azimuth systems lead to lower fuel consumption [5].

When using the VSP there is no need to counteract with the propellers when no or only low amount of thrust is requested. This all leads to cost savings and has a positive effect on the environmental footprint of the vessel [5].

Fig. 15. Fuel consumption [5].

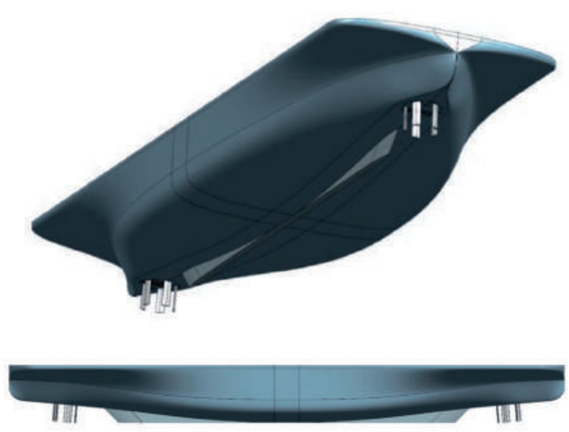


Tailor-made propulsion solutions for passenger ships

Ferries equipped with VSP are reliable and efficient, and do what their operators require of them. They steer the vessel with unrivaled precision and response, particularly important in strong currents, crosswinds, tidal streams and with variable water depths [6].

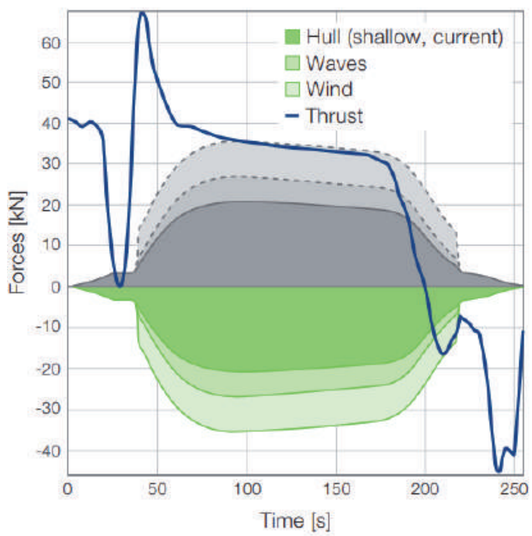
Only the blades protrude from the hull, with all other parts located safely inside the vessel, easily accessible for maintenance. High reliability and long maintenance intervals minimize the cost of ownership. Hull design optimization, high system efficiency and the typical operational profile of a VSP driven double-ended ferry – lower transit speed due to swift berthing and unberthing – all combined with the implementation of combinator mode guarantee significant reductions in energy and thus fuel consumption and emissions [6].

Fig. 16. Optimized hull design for great maneuverability and hydrodynamic effciency [6].



Using comprehensive CFD calculations, simulator studies and finite elements (FE) structural analyses, Voith can forecast vessel behavior. Fig. 17 represents an analysis of an

Fig. 17. Analysis of an existing double-ended ferry connection [6].



existing ferry under environmental controlled conditions [6].

In America, an interesting fleet of double-end ferry with VSP 21R5EC/1 50-1 and Voith electronic control system; also, for Canada, with VSP 18R5EC/1 50-1 represent Voith systems in service with an outstanding performance. For each electronically controlled propulsion system, a perfectly matched remote access capability let the inspection, and the condition-based maintenance strategy support the vessel in a proactive action.

Fig. 18. Remote access for electrical controlled double-ended ferry on service [6].

Most reliable technology for special purpose vessels

For the case of military (Navy) or governmental applications, an interesting installed base over several minehunters, buoy tender and multipurpose vessels with remarkable reliability, highlight the need to maneuver accurately and quickly, spreading minimal dangerous signatures (noise, magnetic and electrical), also guaranteeing high shock resistance. It can even operate in rough weather, high seas, and strong winds to increase mission capability [2].

As remarkable advantages, the integration of the VSP into the hull, as only the blades protrude from the hull. There is no further hydrodynamic resistance due to struts, pods and keel appendages as is the case of traditional propellers. Also, the extremely good positioning response in limited sailing areas, the low noise level to raise the comfort of those on board and the small amount of space required allows installation closer to the ends of the ship. This increases the effective leverage, allowing power to be reduced with respect to conventional transverse thrusters [2].

Fig. 19. Modern MCMV vessel with VSP [2].

The Potential of the eVSP for South America needs.

In South America several projects under development push for the need of highly reliable and efficient solutions capable to support special sailing, aggressive

Fig. 20. Noise difference: Voith vs mechanical thrusters. Source: Lloyd's Register Report 1 3.3720: Noise and vibration measurements [5].

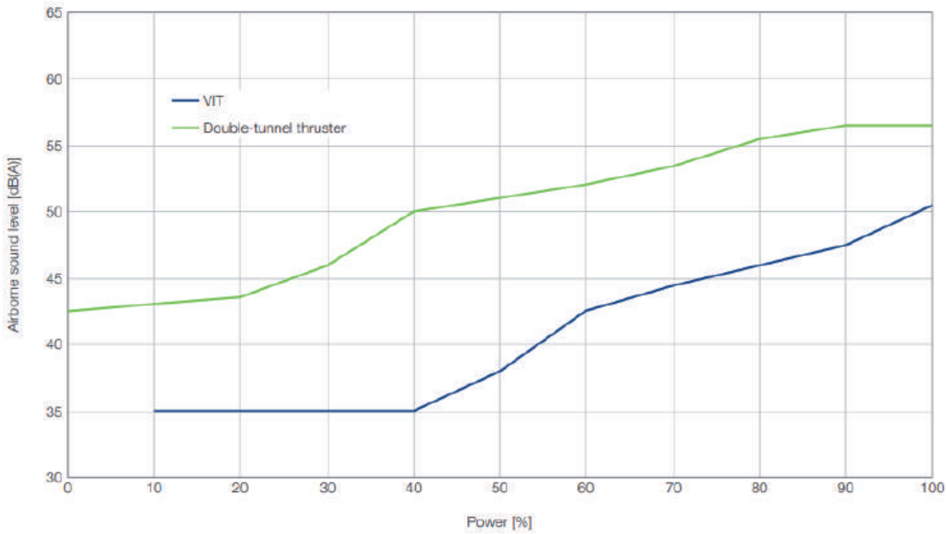
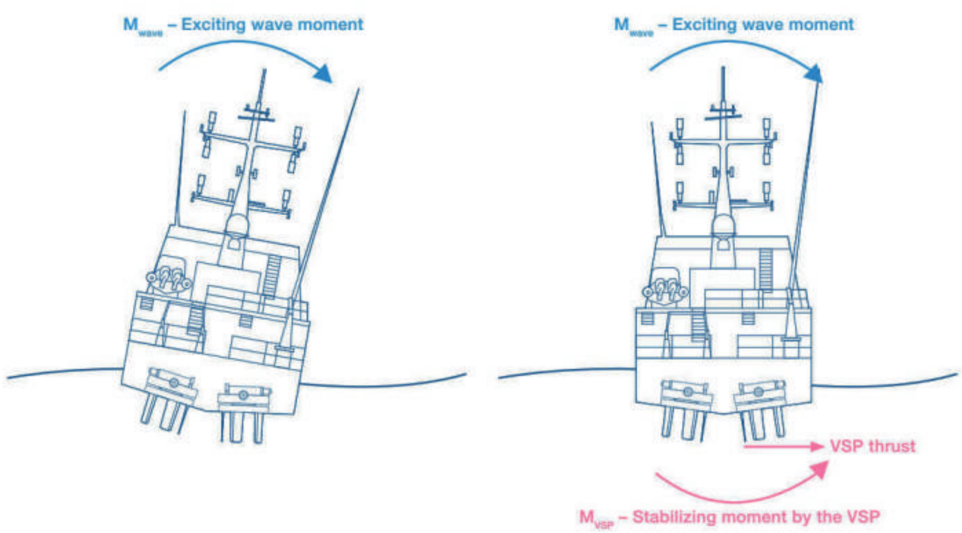


Fig. 21. Moments and forces during ship's rolling [2].



environmental and operational conditions. In this way, the eVSP represents an exceptional alternative. Some features of the eVSP become particularly prominent: first-class Dynamic Positioning (DP) capability; the very uncomfortable rolling motion that can be significantly reduced (in many cases eliminated) with the Voith Roll Stabilization System (VRS); the new blades optimized by CFD to provide a very smooth sailing with the possibility of 6 or 8-bladed rotor with less size for low depth conditions; no shaft line (only cable connection), no gears (no loss, no noise), no external electric motor, less oil volume (-35%) improving the weight and space that could be optimized from early stage design considerations.

About *Brazil*, with the reactivation of the pre-sal exploitation (O&G), the requirement for new buildings of offshore applications as OSV, PSV, AHTC, FPSO, also tugs for escort purposes and pushers for inland navigation at the Hidrovia (Paraguay-Parana) including cargo and shipping containers transportation is increasing the local shipyard developments.

About *Peru*, with the development of new multimodal port terminals, several tugs will be requested for harbor support, even pushers for oil transportation. For the case of their navy fleet modernization, governmental agreements have been signed for the development of new oceanic patrols and research vessels.

About *Colombia*, considering their intention of O&G exploration on the Caribbean coast, also in the Antilles (Guyana & Trinidad-Tobago) tugs and offshore support vessels still on the orderbook. For the exploitation of tourism considering inland navigation, some projects related to Cruise ferry are on development. In addition, with the navy fleet modernization plan, humanitarian landing craft, patrol and research vessels are on the pipeline.

About *Chile*, as it is the country in the region with the largest fleet of tugs supporting several ports. The development of new vessels, still in progress. Some ferries for passenger transportation in the south, oceanographic fishing research vessels, also live fish carrier ships, including navy units, push their local production plans.

About ECUADOR, several applications for tourism in Galapagos Island, their merchant fleet of purse seiner vessel renovation and governmental multipurpose vessels for humanitarian support, make an interesting scenario.

About ARGENTINA, their need of self-propeller barges and pushers for cargo inland transportation and new polar class patrol vessels, also remain an interesting market to be considered.

Conclusions

After almost a century of operational successes of the Voith Schneider Propeller (VSP) onboard thousands of vessels around the world. Today, this fully electric propulsion system is now ready to continue the legacy and set a new standard for efficiency, eco-friendliness and high-performance maneuvering solutions for quiet running and smooth navigation. The expectations of this new development have been completely fulfilled. The first ships are sailing with the eVSP showing an exceptional behavior and response. Considering the improving market of Latin America (growing fast), their special environmental conditions, the operational challenges and even, some political restrictions. The long-standing dream of a technological revolution in the maritime industry—driven by electrification, digitalization, and decarbonization—has become a real opportunity to explore the most sustainable and reliable propulsion system: the eVSP by Voith.

Contributions

- MSc. Edgard Mulford: Contribution (Conceptualization, methodology, regional market analysis, writing and presentation)
- Dr. Dirk Jürgens (not listed as co-author): Contribution (Basic research, hydrodynamic analysis, computational validation, review and head of department)

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