# Propulsion Technologies for Ships –

## Many New and Revolutionary Developments

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Offshore Patrol Vessel with two Voith-Schneider Propellers (VSP). Photo: MF 3/10

Watercrafts are the oldest means of transport of mankind and allow amazing energy efficiency. This is the reason why even after 5,000 years the largest share of transports is still carried out with ships. This high energy efficiency results from the fact that the resistance of a solid body towed through the water becomes increasingly lower with declining speeds and that there is no energy needed for the carrying of loads – as heavy as they may be – as this is performed by the hydrostatic buoyancy (Archimedes). This is impressively reflected in the "von Karman-Gabrielli" diagram (Picture 1). With reference to the performance per transport unit and distance – even when considering the required time – displacement ships are unbeatable.

One could now get the idea that such an old technology as ship construction counts among the "ancient technologies" where no new developments take place and where the word innovation is out of place. No ship owner would order a ship today whose construction documents are 10 years old or even older than that; in the "highly innovative aviation industry" this is common practice of the airlines, however.

The propulsion of a vessel is affected by the propelling unit, which needs to be fed with energy. This energy can be gained from regenerative energies or fuels or a combination of both. Picture 2 shows a rough overview of the classification of the propulsion complex (propelling unit and propulsion) by making full use of regenerative energy. Well-known active principles and mechanisms are shown which make the forward thrust of a watercraft possible. High hopes are placed on wind energy which, when there are sufficient winds, could contribute part of the necessary forward thrust as accessory or additional propulsions. In contrast to the „simple" sails there are, thanks to new materials and intelligent electronics, wind-propelling elements like Skysails[1] available today, which are ready for professional employment.

The disadvantage of all regenerative energies is the question of availability and storage, especially since ships are independent, mobile systems, which have to be available at any time for security reasons alone. Therefore the question arises whether it wouldn't be more favorable to "exploit" the regenerative energies on a technically large scale in order to generate, by means of conversion, fuels of high energy density.

## Big Differences in Total Efficiency Rates

When turning to the propulsion complex by utilization of fuels, we find two classes of subcomplexes, those with mobile elements and those without mobile elements (Picture 3). Propulsion complexes with mobile elements dominate in everyday use i.e. there is usually a power machine (engine) and a working machine (propelling/drive unit) which are either rigidly or flexibly coupled with each other and where mechanical energy is converted on the basis of different active principles into a forward thrust impulse.

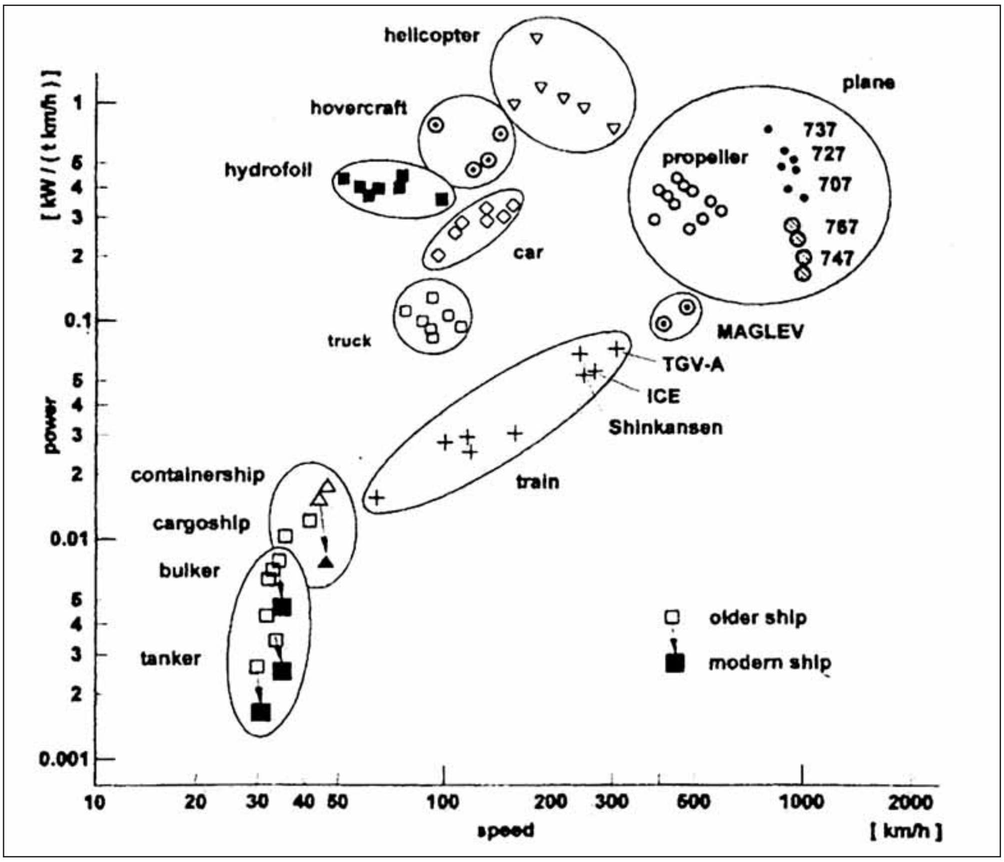
The generation of the mechanical energy is affected by either combustion that can be produced hot (e.g. explosion engine) or cold (fuel cell) or by conversion of electrical energy, which can again be gained through combustion or from regenerative energies.

As for the engines, which generate the mechanical energy by combustion – to be mentioned here as examples are the piston machine, the rotary piston machine or the gas turbine – the efficiency rate is possible to be further boosted only by increasing the process temperature or by secondary aggregates, which recover the process waste heat. In this way major diesel engine systems reach total efficiency rates of more than 60 percent[2]. Aside from the performance the power density kW/kg plays, of course, an important role here, too, since the weight of the system represents a limiting factor especially with fast vehicles. Fast-running diesel engines and gas turbines meet these requirements better, but with lower efficiency rates than the slow-running diesel engine. Especially the gas turbine „power package" shows considerably lower efficiency rates; today's industrial gas turbines for land systems without power-heat coupling achieve efficiency rates of approximately 40 percent. Rotary piston engines are increasingly made use of again for smaller performance ranges, as these have reached a higher reliability due to the application of new materials.

## High Temperature Superconductor Technology and Fuel Cells

When talking about new materials in connection with power density, there is no getting around from a discovery which was made in 1911 – the superconductivity. Superconductivity means a physical effect, which reduces the conduction resistance of materials below a certain temperature to zero. Usual metals show as supraconducting transition temperatures values of less than 7 K (-266° C); this would require liquid helium as coolants, which does not make a technical application very expedient. The discovery of the high-temperature superconductor (HTS) in 1986, which allows resorting to the considerably cheaper nitrogen, led to a technical application. Here, metallic oxides are used instead of metals where the supraconducting transition temperature is above 77 K (-196° C).

Various companies especially in Germany, Japan, and the United States have advanced the development of generators and engines on the basis of the HTS technology – to be mentioned here are the Siemens Company, Sumitomo Electric Industries, and American Superconductor.




Picture 1: „von Karman-Gabarielli"-Diagram. Grafics: Author

After the development of an HTS generator of 4 MW the Siemens Company has merely concluded the development of a 4 MW HTS engine. The prototype was built and subsequently subjected to trials in 2009[3]. Research projects based on that are described below. The U.S. Navy has the American Superconductor Company develop an HTS engine with a power of 36 MW, which is to propel a Bird-Johnsson AWJ-21 waterjet[4].

But what is so very interesting in the application of the HTS technology for maritime traffic? Aside from the power density, which, due to the stronger magnetic field, results in lower weight and smaller dimensions (there is talk of 30 to 50 percent), there are some improvements in the rate of efficiency (2 percent), which can be higher in the part load field (up to 10 percent in slow rates of sailing). And the comfort was also improved due to the lower noise emission in comparison with conventional electric motors. The HTS technology offers a future range of applications for ships with high electric basic loads like cruise ships, mega-yachts as well as naval vessels.

When mentioning the electric propulsions we ought to finally turn to the "cold combustion" where electric energy is generated by the interaction of hydrogen

| Windenergy | Hydrodynamic Energy | Solar Energy | Wave Energy |
|---|---|---|---|
| Sail | Paddle Wheel | Photovoltaic | Floater |
| Windmill | Turbine | Heating of Liquid and Gases | Pendulum |
| | | | Fin |

Picture 2: Propulsion Complexes by Utilization of Regenerative Energies.

and oxygen. The magic word is “fuel cell”. The working principle was discovered in Germany in 1838 already. With the development of space flights the fuel cell became technically fit for use and with the 212 Class submarine there is a first industrial application in shipbuilding5. If the propulsion performances are faster or when looking at big ships, the installed power of 306 kW is rather modest, however. From the present point of view and in consideration of the required volume – both for the fuel cell and the fuel – which can be pure oxygen, diesel or ethanol by use of a reformer, the employment as an energy source for larger required performances does not seem to be possible in the near future. For port operation or maneuvering runs the fuel cell offers itself as an alternative today already, albeit an expensive one.

## Ship Propeller the Propelling System No. 1

After having described the propulsions by use of fuel cells (Picture 3), let us now turn to the associated propelling units. Before going into detail in respect to the developments, here are some words on the general requirements set for these in ship operation. The propelling unit must be competitive in the price-performance ratio and show a high rate of efficiency with maximum reliability. Therefore the ship propeller was, is and will continue to be the propelling system No. 1 of watercraft. But this does not mean that the propeller must always look the same, leaving the blades aside. When looking at the development of the past 30 years one can’t help but to acknowledge that there has indeed been an evolution. New computational procedures led to new profiles, new blade contours, changed load distributions and, last but not least, new materials have also contributed to that just as changed or new manufacturing technologies (CNC milling of the blades) with increased finishing accuracy and surface quality. Propeller coatings commonly used today already result in longer maintenance intervals with concomitant higher efficiency.

Ship propellers made of fiber composite materials have been developed for 20 years. Their hubs are normally made of metal and the blades of fiber composites, preferably by use of carbon fiber. The lighter weight (savings of 25 to 35 percent in comparison with full metal propellers) effects much smoother running and better comfort. The “AIR Fertigungs-Technologie” Company[6] offers such a propeller with a diameter of up to 3 m and a power of up to 3,500 kW under the name “Contour Propeller” which, as a so-called “intelligent propeller”, can adapt and change its blade pitch autonomously without any mechanical component parts. The design and composition of the material effects an elastic deformation of the blades, which allows an optimal adaptation of the performance and power. As a result it is possible to achieve savings in fuels of up to 15 percent as well as a better accelerating behavior. Another advantage of this layout is the simple replacing of individual blades.

Another propeller offered by “Voith Turbo Marine“[7] relates to the sub-class of surface penetrating propellers. Whereas propellers of this sub-class are normally employed in velocity fields above the employment limits of conventional propellers, the offered „vector propeller” is a surface-penetrating variable-pitch propeller, especially for riverboats of all kinds. Due to the generated lateral forces it is only employed in parallel and counter-rotating modes. This, however, permits to dispense with a rudder system, since the lateral force can be employed for steering thanks to a fast adjustable mechanism in connection with an intelligent control for steering. The Potsdam Shipbuilding Laboratory and Test Plant was involved in the development with several research projects sponsored by the Federal Ministry of Economics and Technology. Because of the considerably bigger active diameter in comparison with submerged propellers, there are improvements in the efficiency rate of up to 20 to 40 percent compared to conventional systems.

Another field of research related to the propeller is that of the reduction of its losses. Since the knowledge of the propeller it has been a constant field of developments and patents with their large-scale technical implementation having mostly been affected batch wise in dependence of the energy prices, falling into oblivion in the meantime. A detailed consideration of that would go beyond the scope of this article. Therefore only such catchwords like inflow and outflow guide devices as well as counter-rotating propellers should be mentioned at this point (patent application by Ericsson in 1836). Apart from that there are devices to improve the inflow such as the “Schneekluth” jet nozzle and as an own, independent development in combination with an inflow guide device the “Mewis Duct“[8]. The achievable savings in power are in the upper single-digit range.

| With flexible elements | | Without flexible elements |
|---|---|---|
| *With movable, rotating elements* | *With movable, oscillating elements* | |
| Propellers | Fins | *Ramjet Propulsions* |
| Waterjet Propulsion | Wave Propellers | Heat Convection |
| Air Propellers | Snake Movements | Gas-, Waterjet |
| Turbojet Propulsion | Steel Tube | Magnetic Hydrodynamic Drive (MHD) |
| Turbo Propellers | Wheel with movable blading | Rocket Engine |
| Wheel with fixed blading | Paddle and Rudder | Utilization of the propulsion forces |

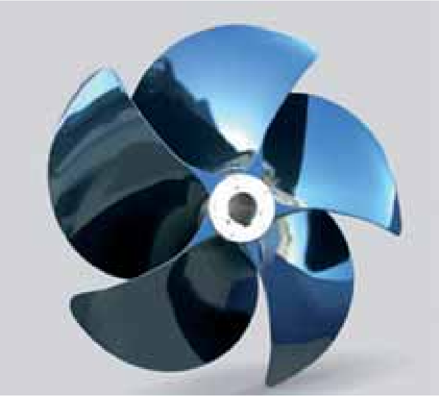
Picture 3: Propulsion Complex by Utilization of Fuels.

## Sheathing and Jet Nozzles

Aside from the free propeller there is also the sub-class of shrouded propellers. Best-known exponent is the jet propeller. The sheathings are classified according to their geometric parameters in acceleration (intake cross section bigger than the cross section right at the propeller) and deceleration jets (intake cross section smaller than the cross section at the site of the propeller).

The classic application of deceleration jet nozzles are towboats and inland waterway vessels, i.e. watercraft with a high shear load of the propeller and high demands on the bollard pull. Additional fields of employment were added with the development of the offshore area, especially in dynamic positioning. To be referred to here are the floating drilling facilities and the anchor handling tug supply vessels (AHTS) with the latter ones having a bollard pull above the 3,000 kN range today.

Under bollard pull conditions an optimally designed propeller jet system realizes a thrust distribution of about 50:50 between propeller and jet nozzle, which results in considerable power savings against comparable free propellers. Whereas standard jet geometry was exclusively applied in the past, modern computational technology combined with suitable numeric procedures makes it now possible to design and employ tailor-made propeller-jet



Contour Propeller with Carbon (left) and without Carbon (right). Photo: AIR

systems. With that, not only the propeller, but also the propeller jet nozzle is experiencing an evolution, which bids the full value of its physical limits.

In a broad sense the shrouded propellers also include the hydrojet propulsions. In their classic form they have sheathing similar to that of a deceleration nozzle and possess an outflow guide device in form of a stator. In principle they also tend towards the axial flow pumps and are also designed like these. Another feature is that the water is suctioned at the bottom and discharged as a jet into the air above the water surface. In this process the water is raised and deflected in its direction. The deeply submerged water jets, which reached their initial operational capability in the past decade, avoid this as intake and discharge ports are on one level. With that there is no additional power required for raising the water and the jet discharge is effected under water which has a substantial influence on the noise development.

Two products of this development are the aforementioned AWJ-21 of the Rolls Royce Company[9] and the "Voith" water jet of the "Voith Turbo Marine Company[10]. In its geometry the AWJ-21 cannot hide its origin from water jet propulsion, whereas the "Voith" water jet tends more towards the jet propeller. In the meantime, research and development in this field have considerably advanced. Here the above-mentioned HTS technologies of the Siemens Company, which provides with its 4-MW engine a respective innovative propulsion source, come to full circle again.

## Pod, Rim Drive, and Voith Schneider Propeller

Innovative propulsion sources are also the topic in respect to the so-called "podded drives" or briefly called "pods". A pod means a propulsion complex, i.e. the unit consisting of drive and propelling device. A big advantage of these systems is the fact that they have to be mounted on the ship from the outside at an only very late point in time of the construction progress; their disadvantage is their heavy weight and their price. After a big euphoria at the time of the introduction into the market there are meanwhile just two suppliers left on the market. The pods themselves are employed with cruise ships and icebreaking cargo ships as well as in special applications and have thus found their market gap. By employing the HTS technology it is possible to considerably reduce their weight and the gondola diameter, which is of importance for the rate of efficiency. In consequence, this will produce development potentials and chances for new applications in the maritime field.

Another pod is – although not in the classic sense – the so-called rim drive. The rim drive is a compact, integrated system, which combines electrical, mechanical, and hydrodynamic elements. The electric motor has the shape of a ring and its stator is integrated into the tunnel or in a jet nozzle, whereas the rotor carries the inward pointing propeller blades. The system does not need any gears or supports and can be employed both as bow thruster and pod[11]. Various suppliers presently offer power packs of up to 800 kW[12].

Whereas all propellers discussed so far have a more or less horizontal shaft, it is essential at this point to also look at the vertical-shaft propeller, which is probably better known under the brand name "Voith Schneider Propeller (VSP)". In the past decade this niche product was advanced in its efficiency by means of new computational procedures and, thanks to modern electronics, extended in its field of application. Extremely fast changes of thrust and the generation of very high moments make it possible to employ the VSP for an efficient reduction of the ship's rolling motion. This is applicable both during sailing and when stopped[13]. Another application of VSP is the so-called cycloid rudder. This is a VSP with two blades, which is employed as rudder in passive operation and as dual-wing VSP with its optimal maneuvering features in active operation. With that it is guaranteed that the main drive can be switched off at slow speed to save energy and also to reduce the signature.

Voith Schneider Propeller for Double-end Ferry.
Photo: Voith

In conclusion it remains to be stated that – despite the fact that the descriptions stay the same – many new and evolutionary developments take place, which will lead to new qualities in due course. Well-known physical principles combined with new computational procedures and fast computers as well as new materials and adapted and new production technologies lead to a steady evolution, taking highest efficiency into account. ■

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### Notes

1 Sky sails, wind power profitably used, www.skysails.info/deutsch/unternehmen
2 An environmentally friendly lady, Maersk Line, www.maerskline.com
3 Full speed ahead. In all-electric ships high-temperature superconductors deliver an efficient propulsion, www.innovations-report.de/html/ berichte/energie-elekrotechnik
4 HTS ship propulsion motors – The next step in marine propulsion, www.amsc.com/products/ motorsgenerators/shippropulsion.html
5 212A Class Submarine, http://de.wikipedia.org/ wiki/U-Boot-Klasse_212_A
6 AIR manufacturing technology, www.voithturbo.com/vt_de_pua_marine_air-fertigungs-technologie-htm
7 The original „Schneekluth" wake-equalizing-duct, www.schneekluth.com
8 The new Becker Mewis Duct®, www.becker-marine-systems.com
9 Advanced waterjets, www.rolls-royce.com/marine/innovation/advanced_waterjets.jsp
10 Voith water jet, www.voithturbo.com/applications/documents/document_files/1586_e_am_prospect_1991_voithwaterjet_engl.pdf
11 Rolls Royce introduces rim drive thruster technology, www.marinelog.com/DOCS/NEWSMMV/2005nov00150.html
12 Voith inline thruster/Voith inline propulsion, www.voithturbo.com/vt_de_pua_marine_air_inline-thruster.htm
13 Voith Schneider propeller for supply vessels of the offshore industry, www.voithturbo.com/vt_en_pua_marine_vspropeller_vspforoffshoresupplyvessels.htm