# APPLICATION POSSIBILITIES OF ELECTRIC DRIVEN PROPULSION OF MULTI-MODE SHIPS

**Jerzy Herdzik**

*Gdynia Maritime University, Marine Power Plant Department*
*Morska Street 81-87, 81-225 Gdynia, Poland*
*tel.:+48 58 6901430, fax: +48 58 6901399*
*e-mail: georgher@am.gdynia.pl*

***Abstract***

*The ship propulsion solution based on unconventional thrusters driven by electric motors is most often applied for the multi-mode ships. These ships ought to have dynamic positioning system. It forces an application of a few thrusters (most often four, seldom more up to eight). Records from a number of multi-mode ships show a mean load of less than 40% of maximum load on the propulsion system. In other side the demand for electric energy of ship industrial part is large, more often than for the propulsion part. In that case the diesel-electric propulsion system application may be economical, because the electric energy generation for all ship's purposes makes possible the main engines work on the optimum loads on lowest specific fuel consumption and allows them a long-term work on heavy fuels. For multi-mode ships like cable ships, suppliers, drilling vessels are convenient an application of unconventional thrusters with direct electric propulsion as well, especially for dynamic positioning systems. The efficiency of the thrusters is a predominant factor for the successful and economical operation. Forecasted development and rise of quantity of diesel-electric propulsion (it means with electrical transmission) would cause increased interest of unconventional thrusters. Ultimately they may revolutionize ship propulsion systems.*

***Keywords***: *ships propulsion, electric propulsion, multi-mode ships, propulsion systems*

## 1. Initial remarks

Nowadays technology allows to create new constructions and to build unconventional marine thrusters, electrical driven propulsion as well. A chance for increasing sell gives a possibility extension of their application and reason of their use necessity. The demand for electric energy of ship industrial part is large, more often than for the propulsion part. The multi-mode ships need a flexible power plant because a mean load of less than 40% of maximum load on the propulsion system. In that case the electric energy is most flexible for all ship's purposes. This is a reason of increasing applications of electrical driven propulsion. Unconventional thrusters as main propulsion are sufficient attractive alternative in connection with tendency to increasing ship manoeuvrability and its independency [5, 9]. They are more and more applied, especially where ship manoeuvrability is more important than fuel consumption and fuel costs.

## 2. Multi-mode ships requirements

In many aspects, the design of a propulsion system for dynamic positioning (DP) applications varies from that of a conventional propulsion system. A conservative design philosophy must be used when designing a propulsion system intended for dynamic positioning. While the design objective for a conventional propulsion system places peak efficiency on or near the systems maximum continuous rating, a propulsion system designed for DP service should be selected and sized to meet the absolute survival requirements [5, 6, 9].

A DP vessel most often is designed to operate in and survive extreme sea environmental conditions, although statistically these conditions occur very rarely. The DP vessel runs at median or lower power levels during the majority of operation. Records from a number of DP drill ships show a mean load of less than 40% of maximum load on the propulsion system [9]. Therefore, a DP propulsion system should be designed for peak efficiency at lower power levels rather than at full load. The standard propulsion system found on a conventional vessel is designed and optimized for the peak efficiency at design point, i.e., the vessel service speed at full of near full power (maximum continuous rating, MCR). It is very difficult for many propeller/drive machinery combinations to match their characteristics for these two modes. Other multi-mode vessels e.g., fishing trawlers, ocean-going tugs, and ice breakers experience have similar problems [9].

For multi-mode ships the propulsion system ought to be design at very small speed near zero and with very good manoeuvring possibilities.

It was utilized in those cases: wide manoeuvre possibilities, safe and speed performance of intended manoeuvre, navigational safety (especially important at heavy environmental sea areas), a possibility of quick change load (often manoeuvres), quick stopping and starting of main engines. In some cases of power plants equipped with main generators, diesel-electric type or gas-electric type, it may be told that the power plant is still in work or ready for work. Every vessel needs the electricity in all operational conditions.

Diesel-electric machinery offers some clear benefits compared to mechanical propulsion. This has made it possible to increase the length of the cargo hold or other application [2, 10].

Correctly dimensioned diesel-electric machinery makes it possible to run the diesel engines close to optimum load in all operation modes. This gives better engine performance and lower fuel consumption. The engines can also be used for many different purposes, which might allow lower installed engine power. This is the biggest advantage for multi-mode ship application.

It must be told that the diesel-electric machinery offers the benefits associated with:

- flexibility - the installed prime mover capacity can be used for different purposes in different situations,
- no need for separate small auxiliary generator sets,
- no need for large shaft generators to power the bow thrusters. Sufficient generator capacity is available when the bow thrusters are needed,
- the diesel engines can be run at constant speed and closer to the optimum load to get lower specific fuel oil consumption,
- freedom in location of generating sets [2].

## 3. Possibilities of electric driven propulsion application

Propulsion for DP ships must provide thrust continuously and efficiently in ahead and astern directions of operation (the best is in all around directions but is to satisfy a thrust vector command at 45 degrees). Selection of the prime mover and/or the selection of the type of propeller is influenced by this requirement.

Nowadays as main propulsion of multi-mode ships will dominate the propulsion solutions with unconventional thrusters. It is seemed to be reasonable to consider more complicated propulsion solutions, for example with two thrusters asymmetrically located on the bow and the stern or with three thrusters where the third one is located on the bow or the stern and may work as a part of main propulsion or as a fully functional bow or stern thruster [5]. The propulsion solution with four thrusters is preferable for vessels with dynamic positioning system (cable ships, pipe laying vessels – Fig. 1, etc.).

The major disadvantage of the ship-shaped drill vessel is its higher degree of motion in waves which reduces its operational efficiency during operations in heavier weather.

The first full-size DP drill vessel exclusively equipped with propulsion devices which allow control of thrust in 360 degrees is the SAIPEM DUE. This vessel is equipped with Voith-Schneider cycloidal propellers [9].

*Fig. 1. Pipe laying vessel „Seven Mavica" [www.subsea7.com]*

The main propulsion is frequently provided by rotatable thrusters which enhances the DP system's efficiency. Transverse forces are generated by tunnel thrusters, retractable rotatable thrusters, or combinations of both.

The capability of generating directional thrust together with the high thrust output of the nozzled propeller (with Kort nozzle) make a well designed and optimized rotatable thruster the most efficient propulsion device for DP applications.

Theoretically, the ducted propeller can be designed for extreme high thrust output at zero inflow speed; i.e. the Kort designed ship has tested a bollard pull specific thrust of most of the propeller/nozzle designs to 0.17-0.22 kN/kW [5, 9]. The thrust is a function of the propeller diameter. A large propeller diameter requires a low propeller RPM at a given power. In that case the peak of propeller efficiency may be increased too.

The availability of devices for the rpm control of AC motors (while operating the power plant at constant frequency and voltage) lead to the utilization of AC motors for propulsion applications. Today, many vessels, ranging from offshore service vessels to cruise ships, are equipped with variable speed AC propulsion drives in conventional, in-line motor-shafting arrangements.

Several large electric companies started with the development of a modular steerable or azimuthing propeller drive. In this drive, the drive motor is installed inside a streamlined housing (pod or azipod). The motor drives directly (or, in some cases, through a reduction gear) a propeller (Fig. 2). An example of this type application is Skandi Marstein. Parameters of the Skandi Marstein propulsion: main engines Wartsila 9L20 4*1470 kW at 900 RPM, main propellers Aquamaster Rauma CRP 25, 2*2200 kW at 1200 RPM (diesel-electric) and bow thrusters: tunnel - Kamewa type 2000H/BMS - FP 736 kW/1200 RPM plus azimuth – Aquamaster type UL 1201/4940/883 kW/1200 RPM. The ship is built in 1996, the IMO No. is 9122978.

The entire housing is watertight and azimuthing for directional control of thrust. This propulsion device is available from approximately 4000 kW to 18000 kW [9]. ABB recently installed 18000 kW drives. CEGELEG and SIEMENS are working on designs and proposals for electric thrusters of various sizes. This type of thruster may be applied for stationkeeping applications in power ranges above 4000 kW per thruster. In total that is enough power for a few thrusters in these purposes.


*Fig. 2. An example of electric driven propulsion – Skandi Marstein [12]*

Many DP vessels are equipped with multiple installations of rotatable thrusters. Reasons for the installation of a larger number of propellers include [1-4]:
- increase of redundancy,
- lower weights of individual thruster assemblies; fewer handling problems,
- availability of large thrusters (thrusters up to 18000 kW),
- high reliability of electrical motors,
- simple construction of electrical propulsion system,
- possibility of compound electrical propulsion system (Fig. 3).

*Fig. 3. Contra-rotating pod propellers with two shafts and two electrical motors [5]*

The main disadvantage of that solution is that this is a new technology, doesn't spread yet. It needs an experience in sea operation.

## 4. Systems of electrical driven propulsion

The most popular electrical driven propulsion is AC/AC System with Variable Frequency Drive and Fixed Pitch Propeller. This type of AC system usually generates medium voltage AC (4160 - 6000 VAC) at constant frequency and voltage. It controls the RPM of the drive motor AC induction or synchronous motors, depending on the type of system by varying the frequency of the system. Three basic system configurations are available for the variable frequency control.

Cyclo Converter: The cyclo converter converts a three-phase AC voltage of constant frequency into a variable three-phase AC voltage with variable frequency. This system is large and expensive, and its major advantage (high torque at zero rpm) is not required for DP propulsion. These drives are typically applied as direct propeller drives on modern icebreakers [9].

Synchro Converter: The synchro converter is typically a six step Load Commutated Inverter (LCI). In conjunction with a synchronous motor it allows load commutation of the inverter and the use of far simpler firing schemes with high power Semiconductor-Controlled Rectifiers (SCRs). The greater simplicity of the control system is the main advantage of this system. Until recently, these systems were only able to control the speed to approximately 10% of synchronous speed. Synchro converter drives were applied to provide quiet propulsion for passenger vessels; the required range of control of thrust was accomplished by controlling the pitch of a controllable pitch propeller in conjunction with the (limited) speed control of the synchronous propulsion motors (Queen Elizabeth II repowering). Advances in the design of the synchro converter now allow speed control over the full operating range, from zero to full speed [9].

The next possibility of electrical driven propulsion application is AC Systems with Controllable Pitch Propeller. A traditional AC system consists of several generators which feed AC of constant frequency and voltage (4160 - 6000 VAC) into a common bus. Either one or several induction or synchronous motors drive the propeller. Its inability to continuously vary the speed of the propulsion motors from zero to maximum is the major disadvantage of this system.

The control of propeller thrust in magnitude and direction has to be accomplished by a controllable pitch propeller. The propeller and its drive machinery operate continuously in one sense of direction. No frequent start/stop maneuvers are required. The absence of high power electronic switching devices increases the reliability of the electric system [9].

## 5. Proposals of electric driven propulsion in the future

It is quested possibilities for other applications of electrical driven ship propulsion. I expect that in immediate future designers of ships would suggest doing multi-mode ships with different types of thrusters, for example ships with dynamic positioning system with azimuth thrusters as main propulsion and cycloidal thrusters as antiheeling device and emergency or support propulsion. The compound propulsive systems containing a few propulsion engines are more reliable. One element unserviceability of propulsive system deteriorates its better manoeuvring possibilities but still gives an ability for individual navigation.

The next proposal is rebuilding existing ships (conversions) for new practical application, as multi-mode ships as well. An example was shown on Fig. 4. This is an offshore floating hotel (flotel) with platform maintenance facilities, rebuilt in 2009.

The propulsion system consists of two 3 MW Rolls-Royce Aquamaster azimuth thrusters on stern and four 2 MW Rolls-Royce azimuth thrusters on midship and two 1.42 MW Rolls-Royce tunnel thrusters on bow. The power generation is composed of 8 diesel engines with HHI generators. The DP (dynamic positioning) system consists of Converteam class 3 system, DGPS/Glonas position reference system, Sonardyne USBL reference system, 3x Gyro compass, 3x wind sensors, 3x MRU's and full UPS redundancy. Accommodation: 399 single man cabins with ensuite facilities.

*Fig. 4. DP III Flotel "Ice Maiden 1" [7]*

Practically every DP propulsion device installed in newly constructed vessels as well as in most of the conversions is driven by an electric motor. It is important that an application of unconventional propulsion doesn't require using the conventional rudder. This function may be to perform by the azimuth thrusters [10, 11].

## 6. Final remarks

In a practice, ships equipped with electrical propulsion system, give a crew an enhanced comfort of work during manoeuvring because of their reliability and redundancy. It must be seen that unconventional thrusters have excellent future as electrical driven ones as well. The total efficiency drop of propulsion is about 6-8% in comparison with conventional propulsion system and increasing fuel consumption, but this is the only one disadvantage. Forecasted development and rise of diesel-electric propulsion systems quantity would cause increased interest of unconventional thrusters, especially azipods. Propulsion of marine thrusters by electrical motors is more and more popular and well-founded. An improvement of propulsive efficiency with unconventional thrusters (for minimizing the efficiency drop) would take to theirs popularization and domination in the end. Ultimately they may revolutionize ship's propulsion systems.

## References


[1] Levander, O., *New propulsion machinery solution for ferries*, Wärtsilä Corporation 2006.
[2] Levander, O., *Combined Diesel-Electric and Diesel Mechanical Propulsion for a RoPax Vessel*, Wärtsilä Corporation, Marine News - Wärtsilä Customer Magazine, Nr 3, December 2001.
[3] Levander, O., Sipilä, H., Pakaste, R., *ENVIROPAX ferries make promising progress*, Marine News - Wärtsilä Customer Magazine Nr 1, 2005.
[4] The Specialist Committee on Unconventional Propulsors. The Final Report and Recommendations to the 22nd ITTC.
[5] Sasaki, N., *The Specialist Committee on Azimuthing Podded Propulsion Report and Recommendations*, ITTC Fukuoka 2008.
[6] Rawson, K. J., Tupper, E. C., *Basic Ship Theory. Ship Dynamics and Design*, 5th Edition, B&H 2001.
[7] DP III Flotel „*Ice Maiden I*", Adams Offshore Services Limited, 2008.
[8] Leavitt, J. A., *Optimal Thrust Allocation in a Dynamic Positioning System*, 2008.
[9] Dietmer, D., *Principal Aspects of Thruster Selection*, Dynamic Positioning Conference, Houston 1997.
[10] *Steerable Thruster Solutions*, Wartsila 2005.
[11] VSP Brochure 2008.
[12] *Skandi Marstein Brochure*, DOF 1996.