A Diagnostic of Diesel-Electric Propulsion for Ships

Newton Narciso Pereira[a]

Abstract

The main objective of this paper is to present an analysis on diesel electric –DE– propulsion systems used on naval, maritime and fluvial ships. There are many advantages and some disadvantages of this system; besides, new propulsion systems have been developed to aid in the maneuvering and steering of ships. Recently, electric ships have employed a very interesting architectural arrangement and these technologies permit achieving more efficiency and a reduction of operational cost and weight. Considerations for propulsion systems utilizing the various types of machine technologies such as the Azipod system are also discussed.

Key Words: Diesel-electric propulsion system, azipod propulsion, maneuvering, steering.

Resumen

El objetivo principal de este trabajo es presentar un análisis del sistema de propulsión diesel-eléctrico –DE– usado en embarcaciones navales, marítimas y fluviales, el cual presenta muchas ventajas pero también algunas desventajas. En la actualidad, se han desarrollado nuevos sistemas de propulsión para ayudar en la maniobrabilidad de los buques aumentando su capacidad de giro y de sostener el rumbo. Recientemente, las embarcaciones con sistemas eléctricos han empleado una disposición general muy interesante ya que esta tecnología permite lograr una mayor eficiencia con la consecuente reducción de costos operativos y de peso de la embarcación. Igualmente, se discuten consideraciones sobre los sistemas de propulsión que utilizan varios tipos de tecnología de maquinaria tal como el acimutal o azipod.

Palabras clave: Sistema de propulsión diesel-eléctrico, propulsión acimutal, maniobrabilidad.

Fecha de recepción: 21 de octubre de 2007
Fecha de aceptación: 3 de diciembre de 2007

[a]University of São Paulo. Department of Naval Architecture and Oceanic Engineering.
Correo electrónico: newton.pereira@usp.br – newtonnaval@gmail.com

Introduction

Several ships have recently employed electric propulsion systems motivated by factors connected with gain in maneuvering and steering, and reduction of fuel consumption and environmental impact. Other factors are related with new options of machine arrangement, better control and more torque capacity and a softer transmission. The use of diesel electric propulsion or DE is not recent. The first electric propeller system appeared in the end of the XIX century in Russia. This ship was used for passenger transport and it was powered by a small block of batteries (Arpiainen et al., 1993).

The same propulsion system was installed on the *Neptune Ship* in 1913 (Soler & Miranda, 1997). In the last century, electric systems were applied in naval, merchant maritime and riverine ships and along the XX century those systems have been improved due to technological advances. In that period, a milestone in the development of electric ships took place between 1911 and1913, when the American Navy installed a 5500 HP in the *Collier Jupiter.* This ship operated successfully over a 30-year period, which was terminated by warfare activity in 1943 after serving as the US Navy's first aircraft carrier Langley.

In riverine navigation, that application was widely disseminated in the United States, when the American Navy built their first "lightships" with DE propulsion systems to operate in the American waterways from 1913 to1938. In the riverine environment, Luna was the first DE fluvial merchant tugboat built in 1932 in the EUA. That represented a big step in the evolution of electric systems, because this propulsion system had a small weight General Electric main motor with 516 HP (411 kW), that offered good internal space distribution. Besides, this system allowed an optimization of propeller speed by using an instantaneous speed controller to change the motor speed in eight ranges of different ship speeds (Luna Preservation Society, 2006).

In 1936, a big DE fluvial tugboat called the Sir Montagu' was built in England. It navigated the Thames River and had a displacement of 61 ton and an installed power of 440 HP (323 kW).

With systematic evolution, the CA-CC system was used in Russia in 1976 on the icebreaker class Kaptan Ismaylov with 2.5 MW power installed, where it already used electronic devices to control motor speed. In 1986, CA-CA propulsion systems were introduced on the icebreaker class Otso. This vessel had a plant projected for the use of thruster control. This year, a project group of Asea Brown Boveri –ABB– from Norway used the Pulse Width Modulation –PWM– inverter for the first time, in the propulsion installation of the ship "Lorelay".

In 1990, the ABB developed a system called Azipod which consists of an electric engine, lodged inside of an adjusted pod to supply better fluid draining, hardwired to a propeller. This set is installed in the external side of the hull and has the capacity to turn 360 degrees around its proper axle and can provide the required thrust in any direction.

Appearring in 1996, a new DE propulsion system developed by Volvo Penta adapted to fluvial ships for container transport in the Swedish waterways. This system was expanded in 1999 and implemented the ecologic ship *Ecoship* concept. The Inbiship, a company of the same group, announced they had developed a new propulsion system in a pod adapted to fluvial ships (Inbiship, 2006).

The shipbuilder Bijlsma Shipyard recently announced, in 2004, the launched of a small LNG ship with a 1100 m3 capacity to operate along the coast of Norway with a mix propulsion electric system. Every main machine is connected with generators to supply 2 electric motors of 900 kW each, with controlled frequency and joint azimuth propellers (Hansen & Lyesbo, 2004). In 2004, the Schiffbau und Entwicklungsgesellschaft Tangermünde- SET built a patrol boat for the German Navy to operate on inland waters using *DE* propulsion system. This ship was equipped with 2 electric motors of 370 kW and an azimuth system and it achieved 12 knots of speed during the operation (Ship and Boat International, 2003).

Nowadays, in France, the Airbus Company uses a fluvial ship with DE propulsion for the transport of fuselage plans along the long Garonne River. This ship has 2 electric motors of 735 kW and a bow thruster of 400 kW (Vacon, 2006).

Finally, in relation to new developments in electric propulsion installations, the Creating Inland Navigation (2006) presents a study on fuel cells for action electric motors installed in fluvial ships in Europe. The basic idea is to change diesel-generators for fuel cells to provide energy to electric motors. Besides, it is environmentally very important because it can provide a big reduction in gas emissions and the noise is insignificant. However, the big problem of this application at present is the high cost and low autonomy of power during a trip.

So, this paper follows a discussion about the use of *DE* propulsion systems presenting the current developments and some more noteworthy future electric ships and technological options as well as their advantages and disadvantages. Additionally, it presents cases of this application in three segments of naval, maritime and riverine ships.

Diesel-Electric Propulsion Characteristics

This system, consisting of an electric generator or alternator, set in motion by an engine is known as DE propulsion, which supplies energy to an electric engine, which sets the propeller in motion. The main characteristic of the DE system is the speed control of the ship by the regulation of the electric engines' rotation. Usually, the electric engines used to possess a great number of pole regions and could be connected directly, or by means of a gear reduction, to the propeller. The capacity and the characteristics of the equipment are those defined by designers, and the modularity of the system allows that, at high speed, all the engines are used, and in economic speeds the unnecessary engines are disconnected (Pereira & Brinati, 2007).

Concerning the propeller element, it can be used as a controllable-pitch and fixed-pitch propeller. However, the former is used more, because the use of the electric engine allows rotation control of the propeller for some bands of operations.

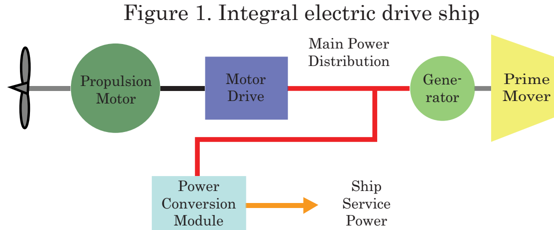
Basically, a propulsion plant DE is composed by the set diesel generator –DG–, frequency converters, electric engines, axles and propellers, and gear reduction when necessary.

McCoy (2003) claims that traditional electric ship propulsion system compare with a mechanical drive system referring to the effectiveness. The electric propulsion system is essentially a transmission for changing the relatively high speed and low torque of the prime mover to the extremely low speed and high torque required to turn the propellers.

Harrington (1970) explains that block Generator – Electric Machine is like an electric transmission. Another important aspect is that the electric propulsion system must also provide for speed change and reversal of the propeller.

A great innovation in the latest years is the Full Electric Propulsion and All Electric Ship where the total integration of the ship's energy consumption is allowed. McCoy (2003) describes in this context that there are two fundamental changes in the way electric drive ships are designed which account for their resurgence. First, there are the high power developments, switching devices and multimegawatt variable speed drives. The second is the shift to an integrated architecture as in the following Figure 1. This system has become common in ships such as tankers, ferries, icebreakers and military. It is very similar to the DE propulsion, with a difference in the concept of rational energy use in the ship. All the energy generated on the ship is used in action electric motors and conditioned to service ship "hotel load".

Figure 1. Integral electric drive ship



Source: McCoy, T. J., (2003).

McCoy (2003) is emphatic in the affirmation that combining the propulsion and ship service electrical systems not only makes the ship more flexible as an integrated electric architecture, but also eliminates the need for shafts between the propeller and the main motors, allowing the ship designer virtually unlimited flexibility in arranging the ship.

Evaluation of this propulsion system Advantages of Diesel-Electric

In this section the advantages of DE propulsion related with conventional applications are presented. The main advantage of the DE propulsion is the speed adjustment of the propeller independently from the rotation of the main machine (machine that generates energymechanics). The adjustment of the propeller rotation is determined by the speed of the electric engine; thus, the main machine works at a constant speed setting in motion a generator that supplies energy to the electric engine. The speed control of the electric engine can be carried out through the invert frequency (CA) or voltage control (CC) applied to the engine.

Arpiainen et al. (1993) present the benefits of this system's output on icebreaker ships. The main advantages of this system are: bigger torque at low speeds and softer transmission systems.

Soler & Miranda (1997) present the minimization in maintenance and operational costs and fuel consumption as an advantage related to electric propulsion. An important affirmation is that electric engines show little cost on maintenance and repair compared with mechanic engines.

In this context, Simpson (1997) makes an affirmation, whena ship uses *DE* propulsion in 30 years the maintenance cost trend is little in comparison with Diesel mechanic ships. As on traditional ships, the motor speed defines the speed of the propeller, in same the conditions, the ship cannot operate at maximum output, in these cases, the fuel consumption is high, but with electric engines this does not occur.

Related with aspects of technique, Soler & Miranda (1997), McCoy (2003), Mezger (1997) claim that the electric propulsion offers advantages in terms of maneuverability, automatics controls, high capacity of reversion engines without the need of special agents and dispense gear box, little gear box noise and vibration in the propeller axle.

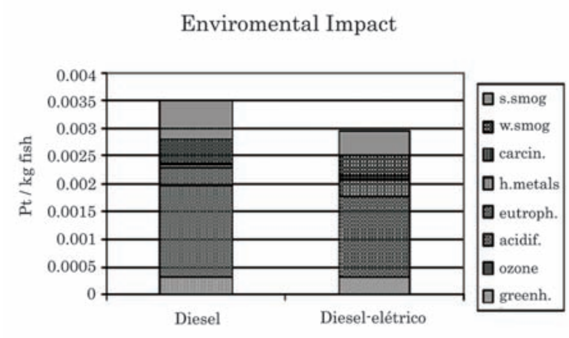
Regarding the maneuverability, Hansen & Lyesbo (2004) explain that the propulsion DE provides advantages for the ship, mainly in the maneuvers of crash stop. This occurs due to the fact that the electric engine provides a better control of the propeller's rotation and to the it's quick change of rotational direction, which reduces the distance and the time of stop. Ships with conventional propulsion can wait until 30 seconds to stop the motor and start the reversion in other direction. For example, we can speak about trimaran RV Triton ship of the English Navy with DE propulsion, when it operates at the maximum service speed of 22 knots, when in crash stop it needs 5 times it's length to stop, but with Diesel propulsion that distance is 10 times greater (FKI Industrial Drives, 2002). In recent studies with bigger DE ships that have demonstrated a reduction from 30% to 50% in the crash stop related to conventional propulsion. In general, a ship with this type of propulsion system has a radius turn 40% smaller than a ship with conventional propulsion.

The Canadian Navy has ships with DE propulsion systems and the tactical diameter is 2.8 time their length, smaller than the recommendation that this parameter not pass 5 times the ship length (Irving Shipbuilding Inc., 2006).

Regarding the environmental questions, Wilgenhof & Stapersma (1997) and the Department of Electric Engineering of the United States Naval Academy (2006) have analyzed the impact of DE propulsion in the environment. They state that DE propulsion reduces the emission rates of pollutant gases approximately from 10% to 20%, compared to the conventional Diesel propulsion.

Ellingsen et al. (2002) developed a model to calculate the environmental impact during the operations of ships comparing the gas emissions with several kinds of propulsion installations, like Diesel mechanic and DE. In the case of fishing ships, authors make an evaluation of the same aspects: acid rain, water eutrophization, green house effect, carcinogens gases, heavy metal and smog. Figure 2, shows the results of environmental impact considering the total power of the ship in function of amount (kg) fished.

Figure 2. Comparison of ship emissions



Source: Ellingsen *et al*. (2002).

Restriction and disadvantages

However, there are innumerous advantages of electric systems, Blokland & Ebling (1995) e Guimarães (1999) call the attention to human safety in the use of electric devices. It is necessary that every person involved in the operation and maintenance of devices are aware and prepared for the risks of these systems. Guimarães (1999) identifies five factors that explain the main causes of accidents: omission, wrong action, immoderate action, lack of control and wrong control.

So, it is important that the crew be prepared to work with accidents that can occur. Note that it is not only about installing more modern propulsion systems on fluvial ships, but also it is necessary to train and prepare the crew with new technologies. Morishita (1985) explains that the human operator is not preparing for managing complex systems that can make their operation inefficient, and therefore very dangerous. Because of this, it is necessary to foster problem awareness since electric systems have high voltage and produce disastrous consequences.

The crew must be prepared to manage system failures, because they can endanger the steering of ship. Borman & Sharman (1995) and Koskela et al. (1995) explain that electric ships must comply with the norms established by classification societies in relation with system failure. Then, it is recommendable to pay attention to:

- Systems isolation of devices in case of short-circuits;
- Proceed to eliminate failures to reduce risk of accidents and avoid fires;
- Separate the power supply of electric engines in two compartments;
- Total separation of vital devices to ship operation in case of fire or flooding compartment.

In the bibliographies analyzed, it could be verified that few authors speak about technical disadvantages of this kind of propulsion system, only detaching positive points. However, Soler & Miranda (1997) make the following observations about the disadvantages of the system like: more cost acquisition of devices in relation to conventional Diesel system, and more weight in relation to Diesel motor. Without trying to have a discussion about advantages and disadvantages presented by these authors, in general a crescent number of ships using DE propulsion in every sector of naval industry have been verified. It points out that despite its high cost acquisition, the benefits gained can guarantee their feasibility in the long run. In Brazil, for example, economic and cultural aspects of riverine ship-owner trends have been a problem for the diffusion of these systems. So, a detailed evaluation must be carried out to verify economic, technical and environmental improvements in electrical ships.

Special diesel-electric pod propeller

The first project of propeller pod was conceived in 1955, when Pleuger and Busmann presented the system and patented it in the United States (Pêgo et al., 2005). In 1990, the ABB launched the same concept of propulsion in the market, but improved for commercial applications. It was called the Azipod. Basically, the system consists of an electric engine, lodged inside of an adjusted pod to supply better draining of the fluid, hardwired to a propeller. This set is installed in the external side of the hull and has the capacity to turn 360 degrees around its proper axle and can provide the required thrust in any direction. The first Azipod was installed on the waterway service vessel called Seili in 1990.

Although there are other companies which manufacture propellers in pods, was determined that given its configurations, during the investigation only the systems manufactured by the ABB would be of interest for Riverine tugboats. In the case of Compact Azipod, that is constructed in 5 different bands of power, that vary between 0.4 MW and 4.2 MW and are ideal for riverine tugboats. These systems can be observed in Figure 3 and Figure 4.

The configuration of this propulsion system can be seen in Figure 5.

Referring to the advantages presented on the electric propulsion, the Azipod extends the range of benefits for this propulsion system. Laukia (1995) points out the following benefits gained with the Azipod system:

- Reduction of the machinery space;
- The system can be used in diverse types of ships;
- Flexibility in general arrangement design;
- The possibility of using a wider design engine market;
- Excellent condition of maneuverability, even at low speeds, because the propellers can be directed towards all of the directions;
- Reduction in the fuel consumption;
- System with high level of reliability; it can be installed in the last period of the construction, some weeks before the launching;
- Low speed operation with low propeller revolutions;
- Excellent maneuverability, propeller thrust can be steered in any direction.

Basically, every aspect about Azipod propulsion system can be seen in Figure 6.

The studies carried out by the ABB and Arpiainen et al. (1993) have demonstrated that ships with Azipod have greater flexibility for accomplishment of maneuvers in risk situations. Laukia (1995) presented the results turn test of ship tanks TM Uikku with Azipod systems and the Lunni with conventional propulsion systems and maneuvering, and

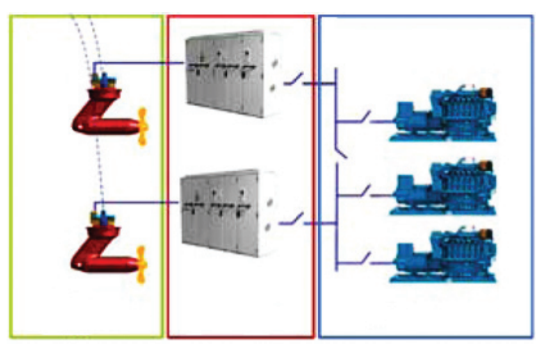
Figure 3. Azipod System

Source: ABB (2002).

Figure 4. Compact Azipod

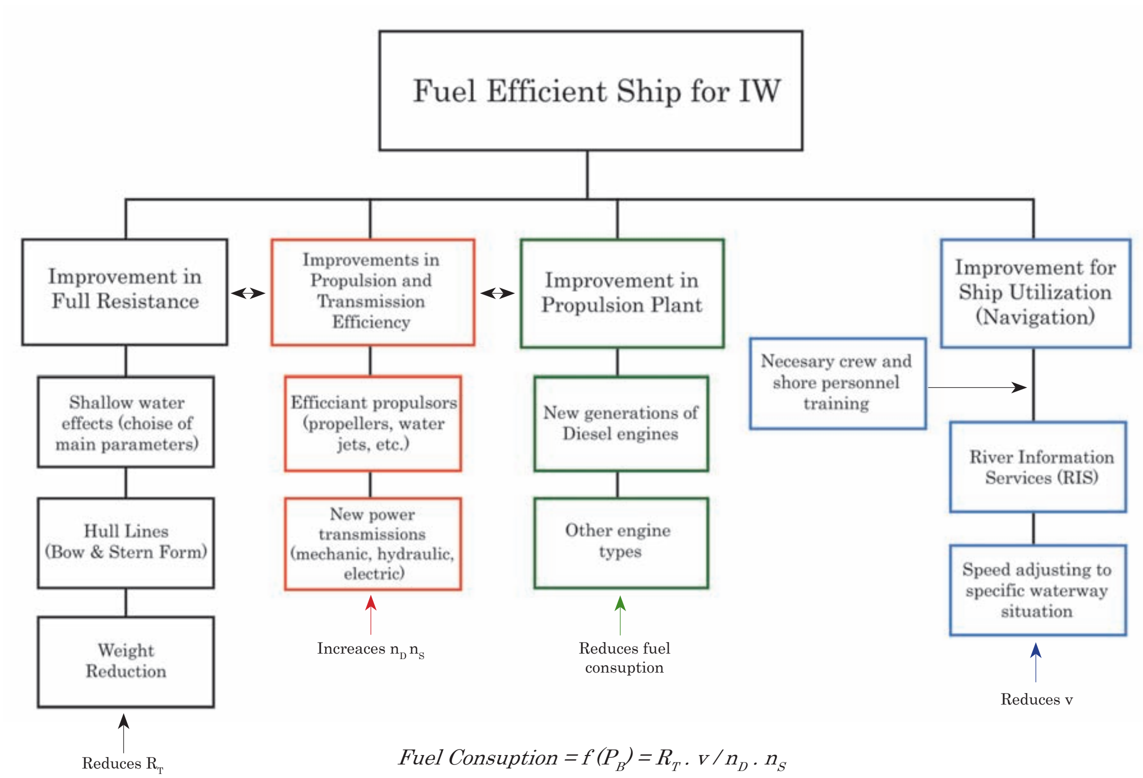
Source: ABB (2004).

Figure 5. Azipod configuration



Source: ABB (2004).

Figure 6. Aspects about Azipod grouped



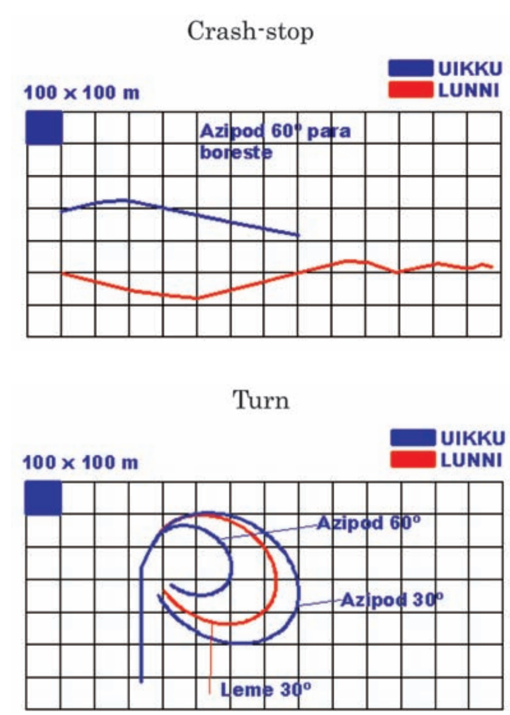
Source: Inbiship (2007).

the results indicate that with the Azipod there was a 50% improvement in the test of turning circle. Moreover, the two ships in the condition of crash stop had been tested, in which the ship with Azipod presented a reduction of approximately 40% in the stop distance. Figure 7 presents these results.

One important result of these tests was the turning capacity achieved with the Azipod; for instance, in 50 cm-thick ice, the radius of the turning circle is decreased by 50%. The turning capability astern is the same as going ahead. Laukia (1995) explain that Uikku has been in operation since January 1994 and some major notes have been recorded in maneuverability, fuel consumption reduction and more capacity of ice navigation.

Regarding equipment installation, Laukia (1995) presents a weight comparison between Azipod versus conventional Diesel propulsion, an example of a 70.000 grt cruise liner. Table 1 shows the results of this comparison.

Figure 7. Crash-stop and turning circle comparison



Source: Inbiship (2007).

In this chart, it can be verified that the use of space in the hull can be optimized in different ways. Auxiliary devices can be located in place of the propulsion motor and some new cabins can be placed in the space formerly occupied by auxiliary devices. So, it can improve passenger accommodations and offer more ability condition for the crew.

Table 1. Weight comparison Azipod vs Diesel propulsion

Diesel propulsion		Azipod propulsion	
Equipment	**Weight**	**Equipment**	**Weight**
Propeller motors	210t	Azipod	340t
Motor Fundaments	30t	Cabling increase	20t
Shaft lines	215t		
Shaft tubes	11t	Steel construction	60t
Rudders, steering gears	54t		
Castings	145t	31 extra pass cabin	60t
Stern thrusters	95t		
Total	**760t**	**Total**	**480t**
		Weight saving	**280t**

Source: Laukia (1995).

Considerations about the use of pod propellers

It is very important to verify that the Azipod substitute conventional rudders, then the hull must do when the flow reaches the propellers. A document of ITTC (2005) explains that for the use of Azipod it is necessary to make some adaptations in the distribution of stern. A main change is the installation of skeg to improve the flow upto the propellers and guarantee more conditions of stability for the ship. It is located in the keel of ship, like presented in Figure 8.

According Mishra (2005), ships that use Azipods, in general have less weight compared to ships with conventional propulsion system. Resulting in less transversal stability, then it can induce roll movements on these ships, it causes a destabilization on the ship. Another aspect is that skeg has an important role in the protection of Azipod in the collision with floating objects and bottom canal.

Figure 8. Skeg

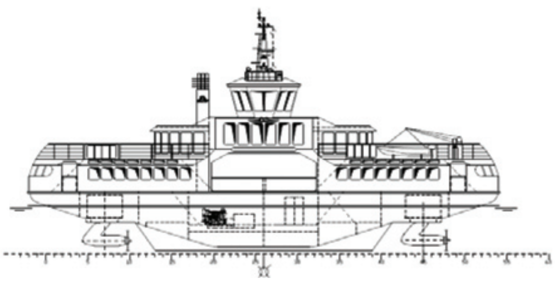
Source: Author's image file.

Figure 9 shows an Azipod installation on a non-conventional ship. This ship is a ferry, that operates on the Finnish Rivers and has a capacity to transport 350 passengers and 2 vehicles. Its dimensions are 33.30m, 8.80m and 3.00m (length, width and draft respectively). It has 2 Compact Azipod with power of 400 kW and achieves a speed of 11 knots.

Regarding the disadvantages in the Azipod utilization, Gragen & Andersen (1997) cite that the system is efficient, but electric synchronous engines have high power and lower speed, that shows disadvantages in relation to the size and weight, making necessary more space for the motor. In general, the approachable pod size corresponding to 60% of the propeller's diameter , the propeller gas relatively slow efficiency, as presented in Figure 10, it shows the effect of the relation pod diameter/propeller diameter on efficiency.

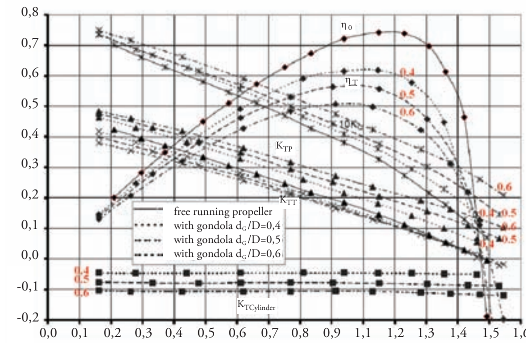
In the same line of research, Heinke & Heinke (2003) carry out tests in three types of pods with different configurations. These authors analyzed the diameter of gondola (dG), in function of length of gondola (lG), and, the lG in relation to propeller diameter (D); because they state that it is an important parameter to quantify the efficiency of the propulsion system. It verified that an improvement

Figure 9. Hull shape on a non-conventional ship



Source: ABB (2004).

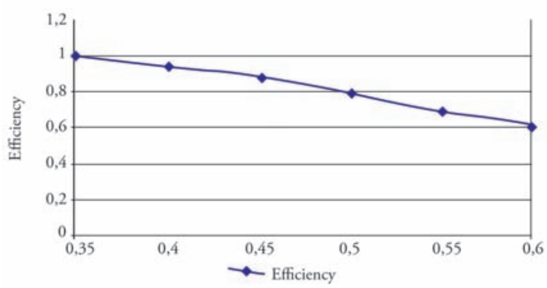
Figure 11. Relation between lenght and diameter pod



Source: Heinke & Heinke (2003).

in the pod length results in an additional thrust and torque in the propeller, but causes a reduction in the total efficiency of the system, as shown in Figure 11. So, the ratio between total thrust and propeller diameter is lower when pod diameter is bigger.

Figure 10. Influence of pod diameter/propeller diameter



Source: Laukia (1995).

Another disadvantage of this system in relation to Diesel propulsion is the cost acquisition of equipments. For example, in the case of big ships like Ropax and cruisers, the cost of Azipod can be approximately €12 million more expensive compared to a conventional propulsion system. This increase in the cost acquisition of the ship is applicable to Ropax ships and cruisers estimated in €100 million and €400 millions respectively.

On the other hand, Turan et al. (2006) shows some problems in the use of Azipod encountered in shiping operations. The biggest portion of these problems are encountered in cruiser ships. A very important aspect is reliability and the maintainability of the ship. They present a reliability analysis of the main equipment of the Azipod. Figure 12 shows this equipment.

They investigated the qualitative and quantitative risk assessments, the crucial components that lead to the failure of the pod system have been identified and the effectiveness of the risk control options such as having redundant subsystems for crucial components have been evaluated. These aspects have a relation with equipments shown in Figure 13.

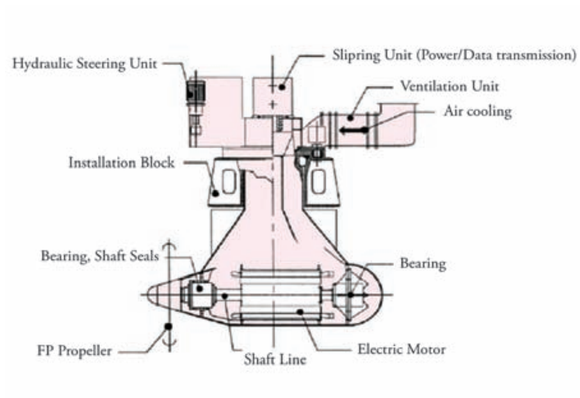
They developed a structure of fault trees for the inclusion of the subsystems/equipment, which cause system effects of "loss of steering" and 'loss of propulsion" for the rotating pod. The time reliability calculated was carried out for operation time up to 10.000 h. During tests, much data was gathered on the failure of this system and it is grouped in Chart 2 to 10000 h operation time and the probabilities of equipments failure are presented in Figure 12 to 6000 h operation time.

As can be seen from Figure 13, the probability of failure of converters increases nonlinearly with time and becomes the highest for the operation times longer than approximately 6000 h. For more than 6000 h this problem is more explicit.

Another important question is presented by Brown and Fisher (2005) about noise generation of Azipod propulsion. The main disadvantage is that the electric motor in the pod is in the water and could contribute significantly to underwater noise. Noise levels from a larger vessel with a larger Azipod were significantly higher than the *International Cooperative for the Exploration of the Sea –ICES–* limit.

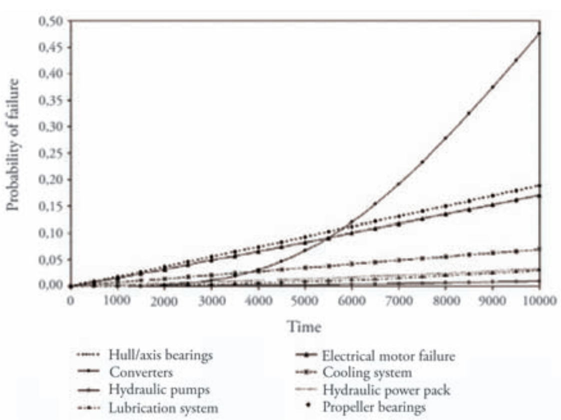
The Azipod may not benefit from applying ICES at lower speeds as shown in Figure 14. The propeller noise will be reduced, but the motor noise could actually increase at lower speeds (Kristensen, 2001). In this context, podded units with the motor in direct contact with the seawater are not necessarily friendly with underwater creatures (Brown and Fisher, 2005).

Figure 12. Azipod system arrangement



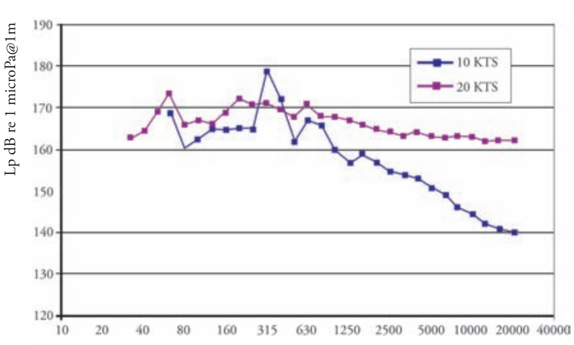
Source: ABB (2002).

Figure 13. Reliability of this propulsion system during in 10000 h operation time



Source: Turan *et al.* (2006).

Figure 14. Noise level of Azipod at lower speed



Source: Brown and Fisher (2005).

Some cases of application

This section presents some DE propulsion systems applications in three kinds of ships. It is very important to verify the uses of these installations in naval, merchant and riverine ships.

Naval ships

Despite the great interest in the application of electric propulsion to warships, there are quite few conventional surface warships with pure electric propulsion, but more are being projected. Electric propulsion for warships does not conceptually differ much from the merchant vessels, but the solutions may differ since the requirements for availability and redundancy are normally stricter. In addition, the ability to withstand shock and provide low noise signatures are prerequisites for electric drive when applied to a warship (Pereira & Brinati, 2007). In this context, the DE became a very interesting alternative to noise reduction on surface ship, because despite the camouflage a reduction of noise will make the ship localization more difficult. The Figure 15 shows the K/V Svalbard, a coast guard vessel in service since 2002 for the Norwegian Navy, equipped with dual Azipod propulsion system, and partially fulfilling military requirements.

Merchant ships

Icebreakers

The vessel is equipped to carry dry cargo, fresh water, fuel oil, liquid mud, cement and barite. Furthermore, the vessel is equipped to remove sewage and waste water from the rigs. Fire Fighting, rescue and pollution control capabilities are installed and the vessel is fitted with towing and anchor handling equipment. The vessel is propelled with two Azipod units, with 1650 kW each and two bow thruster 150 kW each, making the vessel suitable for ice management and navigation through waters covered with ice up to 90 cm and in shallow waters with a depth of 2.5 - 3.0m (Kazakhstan, 2007), like showed in the Figure 16.

Table 2. Failure rate for the elements of pod units

Pod unit	System	Subsystems	Each subsystem (per 106 h)
Thrust equipments	Electric motor	Rotor Stator	0.4
		Stator	2.89
		Mainframe	2.2
		Bearings	3.89
		Temperature sensor	1.8
	Converters	Power components	50
		Control system	68.8
		Power converter cooling system	10
	Shaft	Propeller bearings	3.89
		Thrust bearing	3.89
	Draining system	Water draining, pumps and piping	16.33
	Propeller/hub seals		5.47
	Propeller assembly		0.8
Steering and thrust	Cooling system	Heat exchanger	14.25
		Cooling system, pumps and pipes	4.23
	Lubricating system	Lubricating system, pumps and pipes	38.05
		Lubricating system filters	1.12
	Connection between out and inboard part		0.02
Steering part equipments	Air drying system		13.76
	Hull/axis seals		5.47
	Hydraulic motor		4.5
	Hydraulic pumps		11.6
	Driving gears for hydraulic motors		4.68
	Hull/axis bearings		3.89
	Blocking system		0.04

Source: ABB (2004).

Yacht and Leisure Boat

The power plant of the MY Air (delivered by Lürssen Yachts to her Owner in May, 2005) is similar to the one on the previous yacht, but in lieu of propeller shafts, the MY Air employs two Compact Azipod Units with 2500 kW each, and two bow tunnel thrusters are fed directly from the main 690 V busbar. Ship's service, steering motors and hotel loads are fed from the auxiliary 440V busbar through redundant transformers. The back-up steering motors are fed from the emergency switchboard. Filters are provided to minimize harmonic

Figure 15. K/V Svalbard ship

Source: http://www.sfu.ca/casr/bg-icebreaker-svalbard.htm.

Figure 16. Icebreaker with Azipod system

Source: Kazakhstan (2007).

Figure 17. MY Air Yacht

Source: ABB (2002).

distortion. The installation have some equipments like: 8 x 1000 kVA Main Alternators, 2 x 2500 kW Compact Azipod Propulsion and 2 x 3000 kVA DTC Propulsion Converters, this is showed in the Figure 17.

Tankers

An example is the MT Uikku ship. It is a double hull ice breaking motor tanker with eight cargo tanks and two slop tanks. The ship was built in 1977 in Werft Nobiskrug Gmbh in Rendsburg. The vessel was constructed to the highest Baltic ice class. Ship's propulsion system has an Azipod unit with 11 MW and four diesel generators. In 1998 the hull was strengthened to allow it to sail more safely on the Arctic waters. After the strengthening the hull was stronger than the Baltic ice class. The side view of the ship in the Oulu harbor is presented in Figure 18.

Platform Support Vessel

The Azipod system was applied in the Viking Avant ship. This ship is a platform support vessel and is designed to carry out regular supply and cargo transport functions for the oil industry. The Viking Avant has an overall length of 92.7m and a length between perpendiculars of 84.8m. Its breadth is 20.4m and the depth to the first deck is 9m. It has a 7.5m summer draught (Ship-Technology, 2007), as presented in Figure 19.

Riverine ships

The first application of the Azipod system was on the Seili ship in Finland. Seili was converted from the Diesel propulsion system to the Azipod system in 1990. After conversion, it had 2x1100 KW of main power. The experience with Seili also showed that the vessel could easily be steered when operating astern in ice. The vessel before the modification had the ice breaking capability of 45 cm of level of ice when running forward with a power of 1.6 MW. Because of the rudder arrangement, the vessel was not able to break any ice backwards. After the controllable pitch propeller and the rudder were replaced with a 1.5 MW Azipod unit, as shown in Figure 20.

Discussion

An important discussion about DE propulsion applications can be seen in Figure 20. In general, the use of conventional DE propulsion does not have many chances on the ship related with conventional diesel ships. The main change is the concept of propulsion, because the DE system can offer more flexibility in the operation of the ship and in the maneuvering conditions. So, an important consideration can be pointed out for the uses of DE propulsion on riverine ships. When electric engines are used, the main power can be divided in diverse engines and several diesel-generators are grouped to

Figure 18. MT Uikku ship

Source: Author's image file.

Figure 19. Reliability of this propulsion

Source: http://www.marinelog.com.

Figure 20. Seili ship

Source: ABB (2002).

work in function of the operational requisition of the ship. For example, in the cases of riverine tugboats, the space restriction in the engine room may not allow the use of diverse diesel-generator groups to divide the total power, but it is considered an interesting advantage that can be applied on riverine ships like the passenger and ferry boats. In this investigation, it can be observed that principally icebreaker ship use this type of propulsion system, because of the constant changes in the physical condition of inland waterway, the ship must be adapted for shipping in normal waters and frozen waters, in which for each operational condition the characteristic engine use differ for greater or lesser requirement of power. A similar problem occurs on the riverine convoy operation in the Tietê-Paraná waterway in Brazil, where there are several points with big deep variations and breadth; requiring that the ship operate in several ranges of power to maintain the same speed. Then, it became interesting to adjust the speed of propeller for these speed ranges that do not occur in fulltime and considering that in this condition an increase in the fuel consumption does not occur. Besides, an aspect that causes preoccupation in the ship operation is the maneuverability in the restricted way. In the cases of crash stop it can be crucial to avoid a collision or any other accident.

However, it can be arguable that the flexibility of allocation engines in others compartments on the ship; in tugboats this parameter is very important, because it can offer advantages in two aspects. In the first place, this process tends to facilitate the inspection and maintenance of motors. Generally, these type of ships present small spaces for the engine rooms that, in some cases, make the inspection and repair difficult. Secondly, it should be considered that DE propulsion system arrangement must be subordinate to the arrangement of the ship. The question of stability is also very important and must be evaluated carefully, as must the requirement to maintain the longitudinal and transversal equilibrium be observed. On the other hand, the Azipod propulsion system needs of some alteration in the conception of the ship, principally in the ship's hull. However, the first system had been installed on a riverine ship. Nowadays, its applications are concentrated in big ships like cruisers, LNG, containers, tanker sand supply-boats. In Europe, there are some riverine ships that use the Azipod system propulsion. There are many advantages presented by several authors, but this system is very expensive and it can make its expansion difficult. Finally, another important question refers to the crew on this type of ship, because modern propulsion systems require people trained to operate these systems. Then a constant training is necessary for the ship's crew.

Conclusion

The conclusions obtained from this study are as follows:

1. The Diesel-Electric propulsion system can be applied in diverse types of ships and can offer a good condition of steering and maneuverability. The advantages are very explicit when compared with the conventional Diesel propulsion system, but changes are necessary in the hull shape of the ship to use the Azipod. It must be evaluated to quantify the advantages in changing a conventional ship to the DE propulsion system. However, the costs of these plants are greater in relation to Conventional Diesel propulsion. Regarding the operational level safety, it tends to be more significant when compared with Diesel mechanic.
2. In general the manufacturer shows only the advantages of this system, but some authors present some problems encountered in the use the Azipod system. Since this system is relatively new, others studies are being carried out for deeper analyses on the problems shown for this system.

References

Arpiainen, M.; Juurmaa, K.; Laukia, K.; Niini, M.; Jarvinen, K., Noble, P., (1993), *Naval Architecture of Electric Ships – Past, Present and Future*, SNAME Transactions, Vol. 101, pp. 583-607.

Asea Brown Boveri – ABB, (2004), *Project Guide for Compact Azipod Propulsion Systems*. ABB OY Marine & Turbocharging.

Asea Brown Boveri – ABB, (2002), "Reliable marine propulsion". 3BFV000245R01 REV E © ABB Oy, Marine and Turbocharging, Adams Oy/F. G. Lönnberg, available in: http://www.abb.com/marine.

Borman, J. B., Sharman, B. P. (1995, October), "Electric propulsion – a view from a classification society", in *Electric Propulsion, The Effective Solution* of The Institute of Marine Engineers, Paper 11.

Blokland, A. J., Ebling, G. H. (1995, October), "Protection of an integrated energy system" in in *Electric Propulsion, The Effective Solution* of The Institute of Marine Engineers, Paper 17.

Creating Inland Navigation (2006), Fuel cell technology in inland navigation. Technical report in the framework of EUA project creating (M06.02).

Department of Electrical Engineering of United States Naval Academy. (2006), "Marine electric drive overview", [on-line] available in: http://www.usna.edu/EE/ee331/Handouts/Electric_Drive.pdf. Accessed in: june 23th of 2006.

Ellingsen, H., Fet, A.M., Aanondsen, S., "Tool for environmental efficient ship design", [on-line] available in: <http://www.iot.ntnu.no/users/fet/Publi-Forfatterskap/publikasjoner/Ensus-ellingsen-fet-2002.pdf>, Accessed in: october 12th of 2006.

Fisher, R.W., Brown, N.A., (2005), Factors affecting the underwater noise of commercial vessels operating in environmentally sensitive areas, Oceans, Proceedings of MTS/IEEE, vol. 3, pp. 1982-1988.

FKI – Industrial Systems (2006), "Drives power novel electric trimaran warship", [on-line] available in: http://www.engineeringtalk.com. Accessed in: june 30th of 2006.

Gragen, U., Andersen, P. (1997, March), New type of permament field machines for diesel electric propulsion systems. Proceedings of AES'97 (All Electric Ship), Paris.

Guimarães, L. S., (1999), "Sintese de doutrina de segurança para projeto e operação de submarinos nucleares". Tese (Doutorado), Escola Politécnica da Universidade de São Paulo. Departamento de Engenharia Naval e Oceânica. São Paulo.

Hansen, J. F., Lysebo, R. (2004, September), "Electric Propulsion for LNG Carriers", *LNG Journal*, pp. 12.

Heinke, C., Heinke, H. (2003), "Investigations about the use of podded drives for fast ships", [Conference], FAST 2003. Ischia. Italia.

Kazakhstan W. (2007), IBSV Antarticaborg.

Inbiship (2006), "New opportunities for inland waterway transport". http://www.vbd.uni-duisburg.de/projekte/projekte/inbiship/home.htm. Accessed in: may 22th of 2006.

Irving Shuipbuilding Inc. (2006) Canadian company capabilities. http://strategis.ic.gc.ca. Accessed in: August 23th of 2006.

Luna Preservation Society, Classic american design with a twist. http://www.tugboatluna.org/>. Accessed in: may 12th of 2006.

International Towing Tank Conference - ITTC, The specialist committee on azimuthing podded propulsion. Final Report and Recommendations to the 24th ITTC. 2005. http://ittc.sname.org. Accessed in: june 23th of 2006.

Koskela, M., Koukkari, J., Kuuskoski, J. (1995, October), Designing an electric propulsion system and power plant for optmum safety. The Institute of Marine Engineers, Paper 15, Electric Propulsion The Effective Solution?.

McCoy, T. J., (2003), Trends in ship electric propulsion. U. S. Government work.

Mishra, B. (2005), Prediction of performance of podded propulsors via coupling of a vortex – lattice method with an Euler or a RANS solver. *Environmental and Water Resources Engineering*. Department of Civil, Architectural and Environmental Engineering. The University of Texas at Austin.

Morishita, H. M. (1985), "Estudo de controlador adaptativo para uma instalação propulsora marítima", Tese (Doutorado), Escola Politécnica da Universidade de São Paulo. Departamento de Engenharia Naval e Oceânica. São Paulo.

Pêgo, J., Lienhart, H., Durst, F. Bradran, O. (2005), "Construction of a test facility for the research of ship propulsion systems", *Emirates Journal for Engineering Research*, 10 (2), 1-8.

Pereira, N. N., Brinati, H. L., "Investigation on propulsive alternatives for fluvial convoys adapted to the transport of ethanol and oil derivatives in the Tiete-Parana waterway", IMAM.

Ship and Boat International, *Europe yards show variety. But can it last?*, The Royal Institution of Naval Architects. July/August.

Ship Technology (2007), Viking Avant - Platform Supply Vessel. http://www.ship-technology.com/projects/viking2/index.html#viking23, Accessed in: October 10th of 2007.

Simpson, R. R. (1997, March), "Full electric propulsion system selection for minimum cost of ownership". Proceedings of AES'97 (All Electric Ship), Paris.

Soler, A. L. R., Miranda, S. L. C., "Electric systems pf naval propulsion". Final Report, EPUSP.

Turan, O., Aksu, S., Aksu, S. (2006), "Reliability and Availability of Pod Propulsion Systems", Quality and Reliability Engineering International.

Vacon, (2006), Vacon propulsion on Airbus A380 inland waterway RO-RO vessel. http://www.marine.vacon.com/_FileRoot/265707.pdf Accessed in may 20th of 2006.

Wilgenhof, J. D., Stapersma, D. (1997, March), "Savings in installed power, fuel consumption and emissions with electric propulsion". Proceedings of AES'97 (All Electric Ship), Paris.