MODERN ELECTRIC SHIPS

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Abstract: The paper describes the various types of electric motors for ships propulsion, including high temperature superconductor motors. An overall volume comparison between the conventional marine motors and superconducting magneto hidrodinamic (MHD) linear thrusters is about one third. An innovative small prototype outboard motor supplied by a fuel cell is also described.

Keywords: P.M. Motors**,** A/C motors, Azipod system, Magneto hydrodynamic Propulsion.

Introduction

Electric ships appeared in 1898 for passenger's transportation in Thames River. They employed dc series motors supplied by acid batteries. The two companies *Immisch Electric Launch* and *Thames Valley Launch* operated with ships having 20 meters length transporting a maximum of 80 people, absolutely safe, as shown in figure 1.

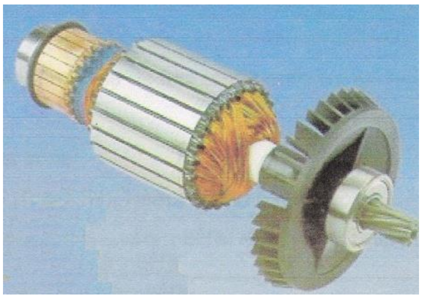

Fig. 1: Electric launches in Thames River and the armature of a dc series motor

The dc motor power used was 1,4 kW having 30 cm in length and weighting 50 kg, shown in figure. The drawbacks were the charge of the batteries, but the electric launch speed was 3 knots, an impressive speed for those times!
The success of the electric launches allowed a wide application in other places around the world such as in Bois de Boulogne Lake, France, and Neiva River, Russia. In 1880 the french Gustave Trouve had the idea to install the dc motor to drive an outer wheel in both boards of the ship. The idea was applied to an electric ship specially designed and constructed for the Emperor Nikolaou I.

In 1913 were installed in the battle ship *USS Jupiter*, synchronous generators driven by steam turbines to supply induction motors directly coupled to the main shafts of the propellers. The motors had wound rotors with slip rings to connected external resistances to help starting. Power of 4.1 MW was developed per each propeller shaft.
In 1922 this ship was transformed in the first electric ship carrier, named as *Langley*, shown in figure 2. She was sunk in 1942.

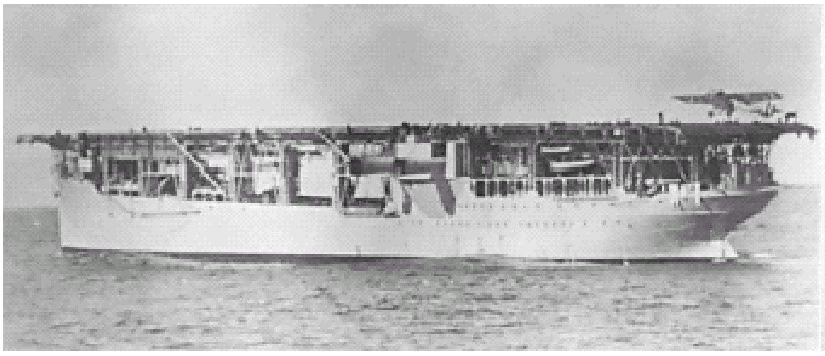

Fig. 2: The USS Electric carrier Langley in 1922

Many other type of conventional electric motors for ship propulsion were developed during last century [1,2] Propulsion of marine vessels using superconducting electric motors may be the most recent for propelled sea water vessels has been studied since the early 1960's [3,4]. A theoretical work describing these fascinating drives is presented.

Convencional electric motors

The main advantage of electric ships is to avoid longer shafts. Since the motors can be installed near the propellers this layout reduces vibration levels and thus the mechanical noise generated. For battle and tourist ships where the manoeuvrability and dynamic response are important characteristics, electric motors are certainly a good solution.
DC machines powered by batteries or recently by fuel cells are used for submarines propulsion when navigating under water. Figure 3 shows a basic magnetic morphology of a two pole dc permanent magnet brushless motor for driving a single shaft submarine. A multiblade propeller is currently used in order to decrease the noise in the water.

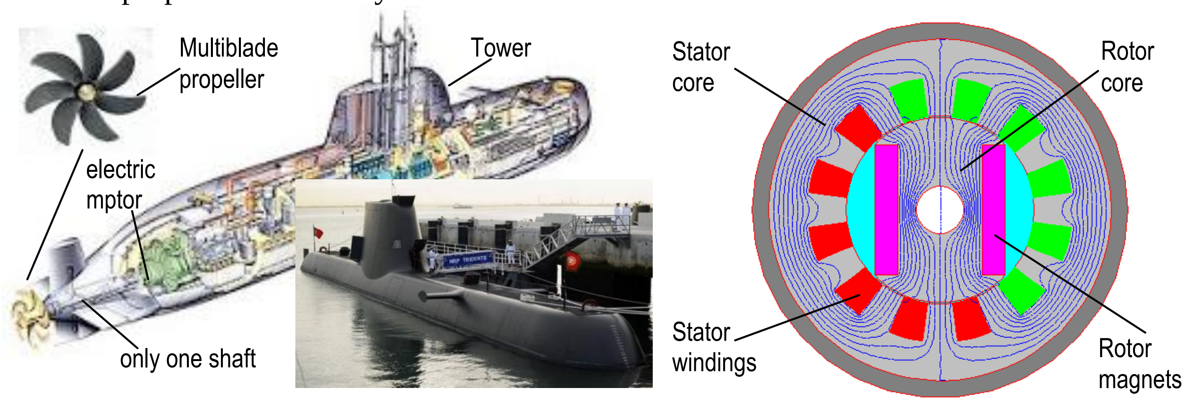

Fig. 3: Submarine and permanent magnet brushless dc motor

Being only one shaft there is an unbalance reaction with the fluid and the submarine tries to rotate opposite to the propeller rotation. However, the submarine tower will compensate this axial movement.

The company ”Alstom” commercialize drum type 20 MW induction squirrel cage motors, as shown in figure 4, able to propel 7000 ship tonnage.
The motors transmit the power to the propellers through a gear down device.

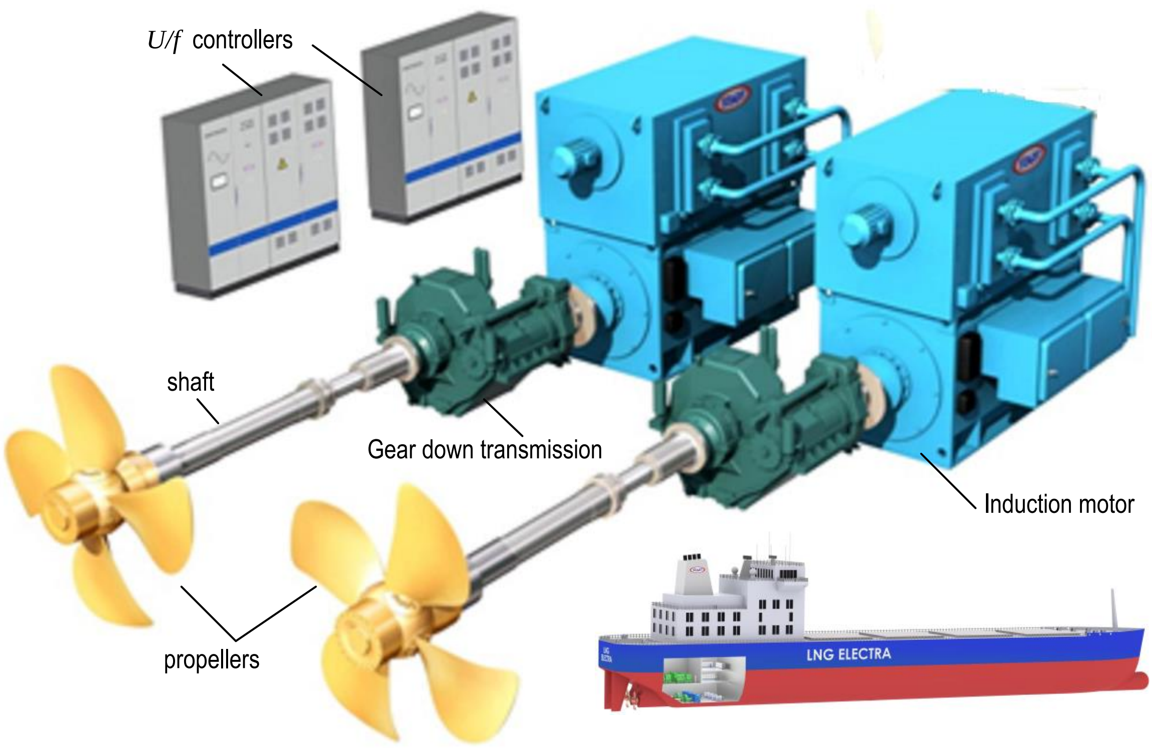

Fig. 4: Squirrel cage 20 MW induction motor

Motor speed control is typically made by using pulse width modulation or *U/f* = Const. methods. A frequency range of 20-150 Hz and simultaneous variation of AC voltage is varied in orden to maintain the ratio *U/f* = Const. This method allows smooth variation of speed with almost constant shaft torque.

“Azipod” system

Recent electric ships, as “Queen Mary II” (2003 and 76000 t) use synchronous motors for ship propulsion installed in hydrodynamic involucres, with an ellipsoidal shape, as shown in figure 5. This arrangement avoids ship ruder and long shafts and it is known as “Azipod” system, after its inventor.

Fig. 5: The “Azipod” system employs 25 MW synchronous motors inside an ellipsoid

For less tonnage and for the sake of space other motor configurations are used as axial and transverse flux motors. Figure 6 shows a section of a transverse permanent magnet flux motor.

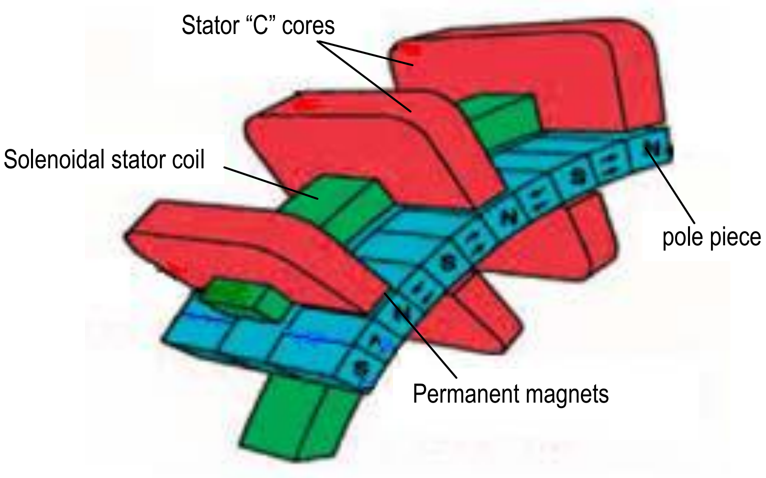

Fig. 6: Transverse flux electric motor layout

A solenoidal coil when excited produces the transverse flux across the stator “C” cores which interacts with the permanent magnets and consequently producing torque.

Superconducting prototype outboard motor

Due to the excellent torque speed characteristics and fast response, disc motors are nowadays widely used in many industrial applications [5]. DC disc motors have the disadvantage to use brushes to feed the armature through the commutater, which is a source of undesirable sparking and wear. Polyphase AC disc motors using Permanent Magnets on the rotor have the advantage to eliminate sliding contacts. However, even using the best PM, as NdFeB, torque per volume of the disc motor is less than the torque produced by the equivalent drum conventional machine.

High Temperature Superconductors are good candidates to replace the Permanent Magnets on the rotor. Although ceramic HTS are very brittle, they can be employed on the rotor construction if an appropriate geometry is used. The disadvantage is the need of using liquid nitrogen (LN_2) to cool down the HTS elements. Nevertheless, the improvement in motor output torque is a great advantage of this interesting machine.

Figure 8 shows the layout of a HTS eight pole disc motor using discs of ceramic HTS material. This configuration is appropriate to incorporate an outboard electric motor as shown in figure 9.

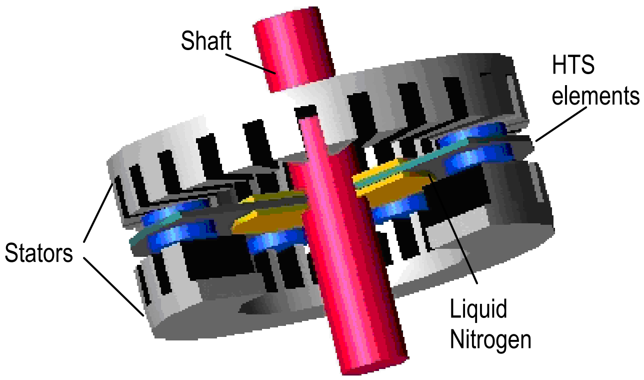

Fig. 8: HTS disc motor

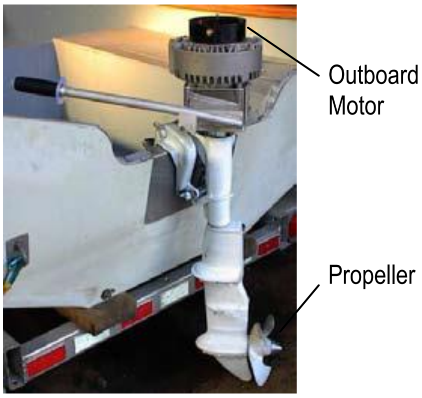

Fig. 9: Outboard motor

Due to the high power density of the HTS motor a 50 HP outboard motor can be constructed with about 1/3 of the volume of the equivalent conventional motor.
The HTS motor is to be fed by a fuel cell. The working principle of a fuel cell, as shown in figure 10, is well known. From the six different fuel cell types, the Proton Exchange Membrane appears to be the most suitable to be applied in transports, and the efficiency is much higher than the internal combustion motors.

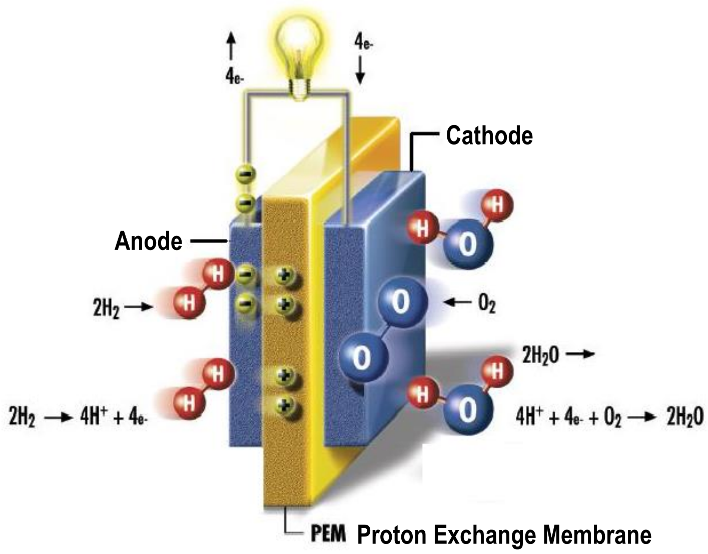

Fig. 10: Fuel cell principle

Fuel cells are being investigated throughout the world and some work is being carried out in FCT/UNL in collaboration of UL. One molecule of the combustible hydrogen $2H_2$ in anode is decomposed in protons $4H^+$ and 4e electrons. Only the protons can reach the cathode through the exchange membrane and the electrons follows the external circuit as an electrical current. In the cathode the protons and electrons react with oxygen O_2 resulting in two molecules of hot water. The technical opportunity of the combination fuel cell/electric motor has been already demonstrated in electric cars. The maritime opportunity to integrate fuel cells, fuel processors and high power density HTS electric motors is the motivation to construct this prototype.

Magnetohidrodynamic (MHD) Propulsion for Electric Ships

If a conductive fluid is crossed by a current density *J* submitted to a perpendicular flux density *B* in a region of volume *abc*, as shown in figure 11, it will suffer a Lorentz force given by *F = JBabc*

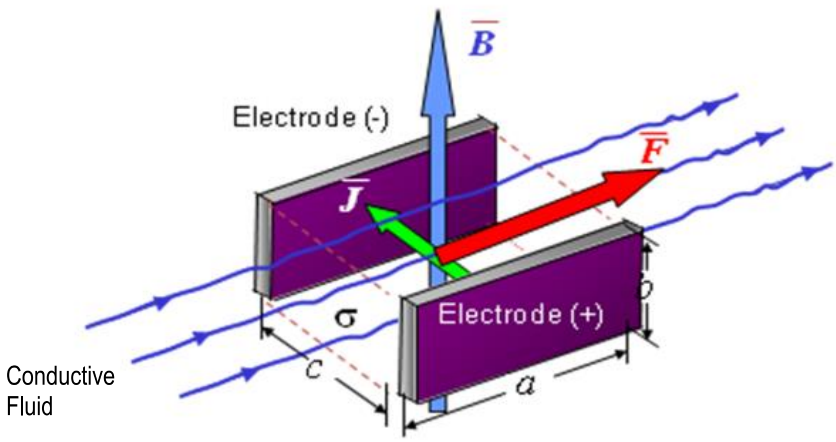

Fig. 11: Lorentz force suffered in a conductive fluid

The current density flowing the fluid is $J = \sigma E$ where $E = U/c$ is the electric field between the electrodes, generated by the applied voltage U, and σ is the fluid conductivity. Then, for a given volume of the fluid the total force is proportional to the conductivity σ of the fluid and the flux density B. Thus, the total force F becomes

$$F = \sigma EBabc = \sigma UBab$$

and it is this force that provides kinetic energy to the fluid. From last equation it can be seen that the kinetic energy of the fluid is proportional to the voltage U applied between electrodes, flux density B and the fluid conductivity σ.

Sea water conducts electrical current by electrolytic ion exchange. Tacking advantage sea water's modest electric conductivity (~3.5 to 4.5 S/m, i.e. 10^{-5} less than cooper), MHD propulsion of marine vessels has been subjected of technical speculation and study for some years. However, in order to have appreciable Lorentz force, flux densities of about 6 to 8 Tesla is needed. These values are only possible by using superconducting coils to provide the flux density.

A layout of a linear dc MHD thruster is shown in figure 12, together with a superconducting saddle-shaped superconducting coil, as shown in figure 13. Both coils are immersed in a cryostat full of liquid nitrogen (77 K) in order to cool the superconductors.

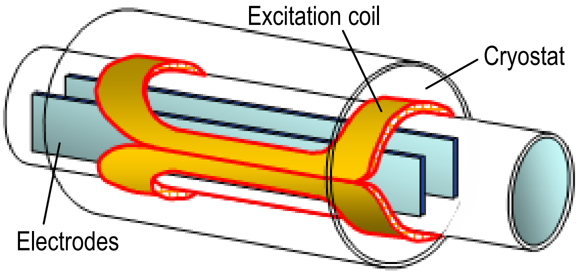

Fig. 12: Layout of linear dc MHD thruster

Fig. 13: Saddle-shaped superconducting coil

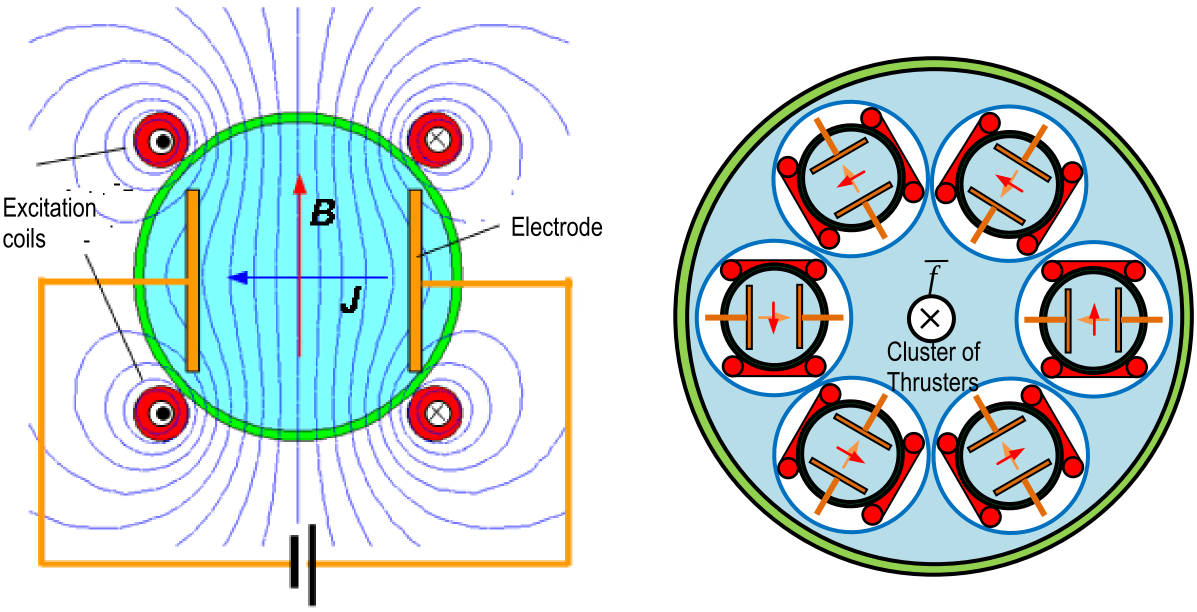

Fig. 14: Layout of linear dc MHD thruster

A cluster of six thruster are mounted together in a tube, as shown in figure 14. Two of these tubes are mounted on both boards outside of the ship. The propulsion results of the water jet, as shown in figure 15.

For a fluid conductivity σ = 4 S/m, a input voltage between electrodes U = 1 kV, and a flux density B = 5T (superconductors) and an electrode surface of $S = 2\ m^2$, the propulsion force in a volume of water between electrodes is $F = \sigma UBS = 40\,000\ N$ = 4 ton.

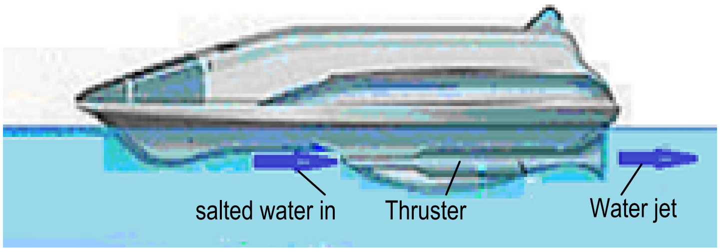

Fig. 15: Prototype of the MHD ship and the Japanese "Yamato" in sea tests in Kobe bay, Japan

The mechanical power developed by the ship is $P_{mec} = Fv$ where v is the jet speed which moves the ship.

CONCLUSION

Conventional electric motors for ship propulsion is now a reality. With the advent of power electronic components (SCR, DIAC, TRIAC, THYRISTOR) allows easy speed control of electric ships.
HTS motors, however, present much less volume for the same power , although a source of liquid nitrogen for cooling the superconductors, and this could be the turning point of the next generation of electric ships.

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REFERENCES

[1] Dionísio, R, “Notes on the preparation of Ph.D. Thesis, Naval School, 2005.
[2] Belvoir, F. “Marine Systems Technology”, Department of Defense, Developing Science and Technologies List, Section 13, July 2002.
[3] Rice, W.A. “U. S. Patent 2,997,013, 1961.
[4] Philips, O. M. “The Prospects for Magnetohydrodynamic Ship Propulsion”, Journal of Ship Research, March, 1962, pp 43-51.
[5] Weh, H, Mosebach, H. Palka, R. “Ship Propulsion with Electromagnetic Direct Drives”, MHDs 91